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PROBE AND RADIATION MEASUREMENTS IN THE COPPER ARC.*

BY

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Abstract. The Langmuir probe has been used to explore the copper arc. The cathode fall of the normal arc has been found to be 20.5 volts, which equals the second ionization potential of copper Cu (II), while the cathode fall for the hissing arc has been found to be 14.0 volts. The potential gradient along the arc stream is constant and therefore the space charge is zero and the concentrations of positive ions and electrons are equal. The average energy of the electrons throughout the arc is between 2.1 and 2.7 volts. The space potential, when measured with reference to the cathode, depends on the current flowing in the arc in the same way as the over all potential, i.e., $V = A + \frac{B}{I^n}$ where A, B, and n are constants. The positive ion concentration in the arc stream increases as the arc current increases according to the equation $n_+ = b\epsilon^{aI}$ where a and b are constants. The light per unit volume has been measured for twelve copper arc spectrum lines and found to

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follow the same sort of equation as above, i.e., $I = ce^{pal}$, where c is a constant, a the constant appearing above, and p takes on values 2, 3, 4, etc. Eliminating the current between these two equations, it is shown that the light intensities in lines λ3248, λ3274, and λ5105 of the copper arc are proportional to the *square* of the electron concentration while the intensities of λ2618 and others are proportional to the *cube* of the concentration, etc. Thus it is demonstrated that the relative intensities of the lines in the arc spectrum are not fixed but depend in a definite manner on the arc current flowing since the excitation is produced as a result of the cumulative action of the electrons in which 2, 3, 4 or more electrons take part.

INTRODUCTION.

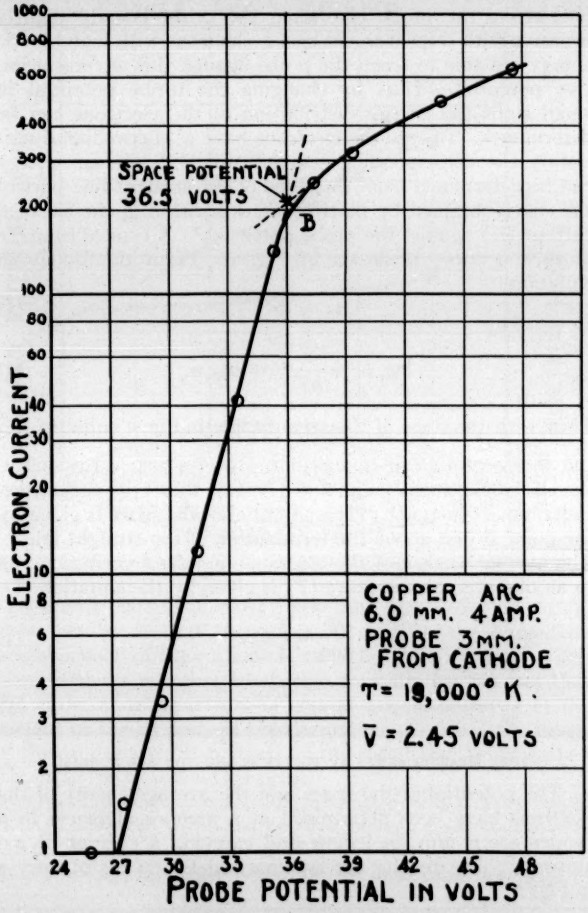
In a recent issue of this JOURNAL, a report was made on the use of the Langmuir probe for the study of the normal electric arc.[1] Those methods have been used to study the normal arc between copper electrodes in order to find (1) the average energy of the electrons in this arc; (2) the distribution of potential along the arc stream; and (3) the positive ion concentration in the central portion of the arc with different currents flowing. A method was worked out by which the variation in the intensity of certain of the lines of the copper spectrum could be measured when the arc current was changed. These results combined with those of the probe measurements have revealed many interesting facts concerning the detailed mechanism of the copper arc which may possibly be common to other arcs between metals at atmospheric pressure.

PROBE MEASUREMENTS.

The experimental procedure may be recalled to mind as follows: a copper wire probe 0.01 inch in diameter is moved through the arc stream at practically a constant velocity of about 60 cm. per second, while the potential of this probe is maintained at a definite value with reference to the negative electrode by means of a low resistance battery. The current which flows through the probe circuit during the passage of the probe through the arc stream is registered on a ballistic galvanometer. When the probe is very negative with respect

[1] JOURNAL OF THE FRANKLIN INSTITUTE, 206, 43 (1928).

FIG. 1.



Semi-logarithmic plot of electron current.

to the space in the arc through which it travels only positive ions strike the probe but when the probe is only slightly negative with respect to the space, electrons with high kinetic energy are able to reach the probe against this adverse negative potential. Thus by changing the probe potential in small steps the energy distribution of the electrons can be determined. In case the electrons have a Maxwellian distribution the corresponding temperature and average energy can be determined from the slope of the straight line part of the curve obtained by plotting the logarithm of the electron current (i_-) against the probe potential.[2] A typical example of such a curve is shown in Fig. 1. From the Boltzman equation

$$i_- = a\epsilon^{eV/kT} \tag{1}$$

we see that

$$\log_\epsilon i_- = \frac{e}{kT} V + \log_\epsilon a. \tag{2}$$

Thus with the slope of the straight line in Fig. 1 equal to $\frac{e}{kT}$, the temperature can be calculated ($e = 4.774 \times 10^{-10}$ e.s.u. the electronic charge; and $k = 1.372 \times 10^{-16}$ ergs per degree, Boltzman's constant). The potential of the space is given by the point B just above the termination of the straight line. The average energy of the electrons in volts $\bar{v}$ corresponding to an observed temperature (T) is given by the equation

$$\frac{e\bar{v}}{300} = \frac{3}{2}kT, \tag{3}$$

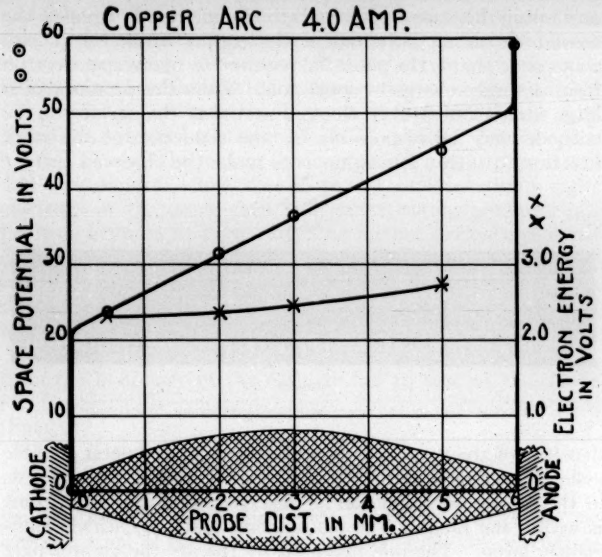
$$\bar{v} = \frac{T}{7{,}732}. \tag{4}$$

PROBE MEASUREMENTS AT POINTS ALONG THE ARC STREAM.

The potential of the space and the average energy of the electrons have been determined at a number of places in a copper arc 6 mm. in length and carrying a current of 4.0 amperes. The results are summarized by means of curves in Fig. 2.

[2] For the complete theory of the probe see Langmuir and Mott-Smith, *G. E. Rev.*, **27**, 449, 538, 616, 762, 810 (1924).

FIG. 2.



Distribution of potential and electronic energy along the copper arc.

Cathode fall: The most important fact brought out by these results is that the potential drop in the immediate neighborhood of the cathode is very close to 20.5 volts. This observation is corrobrated spectroscopically by the fact that the entire spark spectrum of copper can be observed at the surface of the cathode in the normal copper arc if the image of the arc is carefully focused on the slit of the spectroscope.[3] Fig. 3 serves to prove this point.

Over the range of wave-length λ2330 to λ2850 every one of the 35 lines listed by Shenstone[4] can be seen easily on the negative. In arcs previously studied, the cathode fall has been found to be practically equal to the ionization potential of

[3] Observed also by Hagenbach, *Phy. Zs.*, **12**, 1015 (1911).

[4] Shenstone, *Phys. Rev.*, **29**, 380 (1927).

the electrode material (the cyanogen molecule for the carbon arc) but in this case we have a cathode fall exactly equal to the second ionization potential of the copper atom Cu (II) of 20.5 volts,[4] that is the potential required to remove an electron from a singly charged copper ion. Thus the presence of a large number of doubly charged atoms at the surface of the cathode may be responsible for the reduction of the work function to such a low value as to make the observed current

FIG. 3.

Spectrum plate showing copper spark lines at the surface of the cathode.

densities of about 3,000 amperes per square centimeter possible even at a cathode temperature of 2500° K. or less. Two forms of the copper arc in air can be observed when the arc current is within the range 2.0 to 8.0 amperes and the cathode sufficiently large. The one taken on by the arc the greater part of the time has been considered as the "normal" arc and is the one which has received the greater attention. The second form, some times called the "hissing arc," is characterized by greater luminosity in the core and also in the red flame sheath which surrounds the arc while the over all voltage between the electrodes is 7.0 to 8.0 volts less than that required to operate the "normal" arc. If the cathode is only two or three millimeters in diameter the hissing arc is usually the only form found. The fact that the greater part of this change in voltage takes place in the cathode fall has been demonstrated by probe measurements made by Hagenbach [2] in which a high resistance voltmeter was used to measure the potential of a probe immersed in the discharge. Langmuir has shown that the voltmeter does not show the potential of the space but shows the potential at which equal numbers of positive and negative ions reach the probe. The cathode fall

in the hissing arc was measured using the Langmuir method and found to be about 14.0 volts which is 6.5 volts less than that in the normal arc. If the cathode fall in the hissing arc is to correspond to the ionization of the active vapor it must be associated with that of copper oxide or cuprous oxide (Cu_2O) for it is much too high to correspond to the first ionization potential of copper which is 7.7 volts. Since copper has one valence electron in this compound, two copper atoms and one oxygen atom should give a molecule with eight electrons in the outer shell and an ionization potential not far from krypton at 13.3 volts. As further evidence that the cathode fall of the hissing arc is to be associated with the oxide we can take Hagenbach's observation that only the normal form of the arc can be produced in an atmosphere of nitrogen using clean copper electrodes.[5]

The arc stream: The potential gradient along the arc stream from the boundary of the cathode fall to that of the anode fall is practically constant. Since Poisson's equation states that

$$\frac{d^2V}{dx^2} = -4\pi\rho, \tag{5}$$

we see that the space charge (ρ) is zero and therefore the concentration of electrons must exactly equal the concentration of positive ions. The total current flowing along the arc stream is the sum of the electron current (I_-) and the positive ion current (I_+) and these stand in the ratio

$$\frac{I_-}{I_+} = \frac{v_-}{v_+}, \tag{6}$$

where v_- and v_+ are the corresponding ion velocities in a field of 47 volts per cm.

Anode fall: The anode fall is between 7 and 8 volts. The factors which serve to determine its value are not immediately obvious.

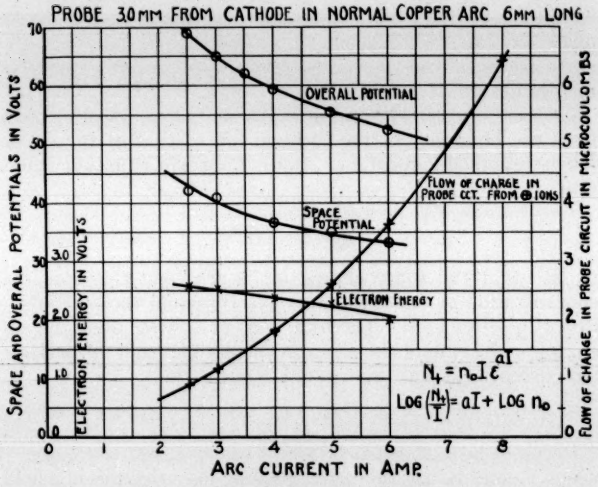
Electron energy: The average energy of the electrons increase slightly as they proceed from the cathode to the anode. These energies are 2.3 ± 0.1 volts near the cathode and 2.7 ± 0.1 volts near the anode.

[5] Hagenbach & Veillon, *Phy. Zs.*, 11, 833 (1910).

COMPARISON OF PROBE MEASUREMENTS IN ARCS CARRYING DIFFERENT CURRENTS.

Copper arcs 6.0 mm. in length and carrying currents ranging from 2.5 to 6.0 amperes were studied with a copper probe moved through the arc stream at a distance of 3.0 mm. from the cathode. The average electron energy, the space potential, and a measure of the positive ion current to the probe were determined in each arc. These results are shown by the different curves of Fig. 4.

FIG. 4.


PROBE 3.0 MM FROM CATHODE IN NORMAL COPPER ARC 6MM LONG
SPACE AND OVERALL POTENTIALS IN VOLTS
ELECTRON ENERGY IN VOLTS
FLOW OF CHARGE IN PROBE CIRCUIT IN MICROCOULOMBS
OVERALL POTENTIAL
SPACE POTENTIAL
ELECTRON ENERGY
FLOW OF CHARGE IN PROBE CCT. FROM ⊕ IONS
$N_I = n_o I e^{aI}$
$\text{LOG}\left(\frac{N_I}{I}\right) = aI + \text{LOG } n_o$
ARC CURRENT IN AMP.

Probe measurements in the copper arc with the probe half way between the electrodes.

Space potential: The space potential at the point half way between the electrodes follows the same form of function in its dependence on the arc current as the over all potential and is given by the equation

$$V = A + \frac{B}{I^n}. \qquad (7)$$

The corresponding values for the constants are $A = 20$,

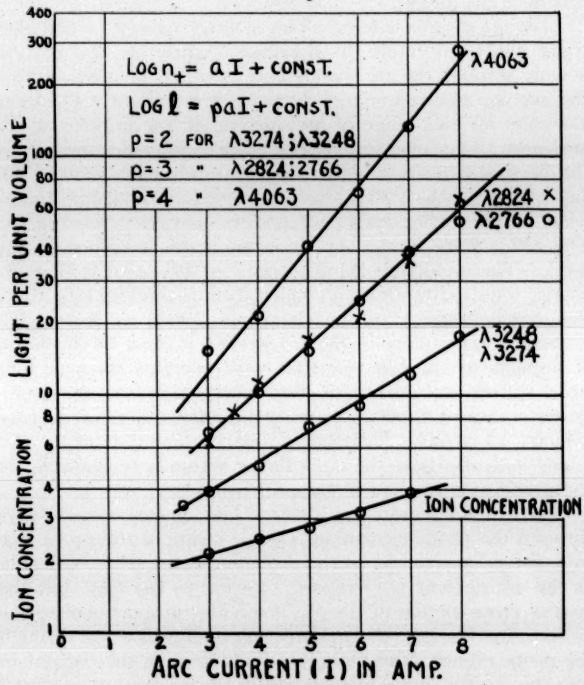
$B = 41$, and $n = 0.64$ for the space potential while $A = 36.3$, $B = 59$, and $n = 0.67$ for the over all potential. Since in general the value of n depends upon the absolute temperature, the lower value of n of 0.64 may result from the fact that the average temperature of the arc is lower near the cathode than it is near the anode.

Average electron energy: The average energy of the electrons has been found to decrease slightly as the current flowing through the arc is increased. From Fig. 4 we see that the average electron energy decreases from about 2.5 volts to 2.0 volts for the range of arc current of 2.5 amperes to 6.0 amperes. This electron energy is probably determined by the electron transition in the copper atom from the metastable "D" levels to the $2^2P_{1,2}$ levels involving an inelastic impact which takes either 2.14 or 2.4 volts energy. (See Fig. 6.) The $2^2P_{1,2}$ state in the copper atom is the lowest radiating level. The important thing to note at this point is that the energy required to ionize a copper atom is three to four times the average energy of the electrons. Since we know that ionization takes place in the arc stream, it must be the result of impacts of the few electrons with energies three or four times the average energy, or else it must result from the cumulative action of three or four successive impacts of average velocity electrons. Evidence to be presented later in this paper indicates that the cumulative action is responsible for the production of most of the positive ions.

Positive ion current to probe: The charge which flows through the probe curcuit in a single swing of the probe due to positive ions coming to the probe increases very noticeably as the arc current is increased. Owing to the fact that the area of cross-section of the arc is directly proportional to the arc current flowing, the positive ion charge flowing through the probe circuit would increase linearly with the current in case the positive ion concentration in the arc stream remained unchanged. The fact that this curve is convex toward the current axis (see Fig. 4), shows that the concentration of positive ions increases as the arc current is increased. The ordinates plotted show the positive ion charge flowing through the probe circuit when at the potential of the space. This is obtained by extrapolating the "voltage-current" curve ob-

served over a range of voltage which is so negative with respect to the space that the electron current is too small to measure. The positive ion probe current, which is a measure of the number of positive ions which strike it and give up

FIG. 5.



Curves showing dependence of light and ion concentrations on arc current in copper arc.

their charges, can be represented by the simple empirical equation

$$N_+ = n_0 I \epsilon^{aI}, \qquad (8)$$

in which n_0 and a are constants. The charge which flows

through the probe circuit when the probe passes through the arc stream of radius r at a constant velocity v can be shown to be given by the equation

$$N_+ = \frac{\pi r^2 i_+}{v}, \tag{9}$$

where i_+ is the current to the probe per unit length. Since the motion due to thermal agitation is large compared to that due to the drift in the direction of the field, the current i_+ is proportional to the positive ion concentration n_+. From equations (8) and (9) and the fact that the area of the arc is proportional to the current flowing, we can express the relation between the positive ion concentration and the arc current by equation (10).

$$n_+ = b\epsilon^{aI}. \tag{10}$$

Here a and b are constants and n_+ is proportional to $\frac{N_+}{I}$. Graphically this relationship is shown by the straight line of Fig. 5 designated "ion concentration." Since

$$\log_\epsilon n_+ = aI + \log_\epsilon b, \tag{11}$$

the value of a is given by the slope of this straight line.

INTENSITY OF SPECTRAL LINES AS A FUNCTION OF ARC CURRENT.

Method of measurement: In order to determine how the intensity of certain spectral lines in the copper arc depends on the current flowing in the arc, it is necessary to have a device whose response is proportional to the light intensity falling on it. The light from the arc was passed through a quartz lens and two quartz right angle prisms adjusted to form an image of the arc on the slit of a D 41 Hilger monochromatic illuminator. The axis of the image was turned into the horizontal position by prisms so that the light which passed through the monochromatic illuminator all came from the small cylinder in the arc syream bounded by two planes passed perpendicular to the axis of the arc and separated by a distance equal to the width of the slit of the monochromator. The arc was so adjusted that this cylinder occupied the samc region which was swept through by the probe when it was set

to swing through half way between the electrodes. The light intensity for the lines between λ4023 and λ5220 was measured by a potassium-hydride photoelectric cell made in our laboratory [6] coupled with a vacuum tube amplifier with a sensitivity of 24,000 mm. per volt and an input resistance of about 2,000 megohms. To measure the light intensity in the ultraviolet from λ2441 to λ3274, the light was made to fall on a glass container with a quartz window and filled with a saturated solution of esculin in water. A part of the fluorescent light produced by the ultraviolet passed into the photoelectric cell and gave a current which could easily be measured. The fact that the fluorescence is proportional to the intensity of the ultraviolet light falling on the container was proved by measuring the change in photoelectric current when the intensity of the ultraviolet light was reduced by interposing various wire screens at the lens. The absorbing power of the screens measured with blue light was found to be the same as that for the ultraviolet assuming the intensity of fluorescence proportional to the incident ultraviolet radiation.

Experimental results: The first lines to be examined were the two resonance lines λ3274 and λ3248 which correspond to the $1^2S - 2^2P_{1,2}$ transitions. Although these two lines could not be definitely resolved, no harm should result since they correspond to transitions so similar in all respects. The results of these measurements showed that the light intensity L followed the same simple empirical relationship found for the positive ion current and given by equation (8). This equation in more suitable terms is given in equation (12)

$$L = l_0 I \epsilon^{aI}. \tag{12}$$

Here the arc current is I, and l_0 and a are constants. Since a negligible part of the radiation of this wave-length originating throughout the volume of the arc is absorbed in the arc, we can take the light per unit volume l as being proportional to $\frac{L}{I}$ and write equations (13) and (14).

$$l = c\epsilon^{aI}, \tag{13}$$

[6] "Instruction on the Making of Potassium-hydride Photoelectric Cells," W. B. Nottingham, JOURNAL OF THE FRANKLIN INSTITUTE, 206, 637 (1928).

$$\log_e l = 2aI + \log_e c. \tag{14}$$

From Fig. 5, we see that the slope of the straight line designated "λ3274; λ3248" is twice that for the positive ion concentration and therefore the constant a is the same in equations (10) and (13). From these two equations, together with the fact that the positive ion concentration is equal to the electron concentration, we see at once that

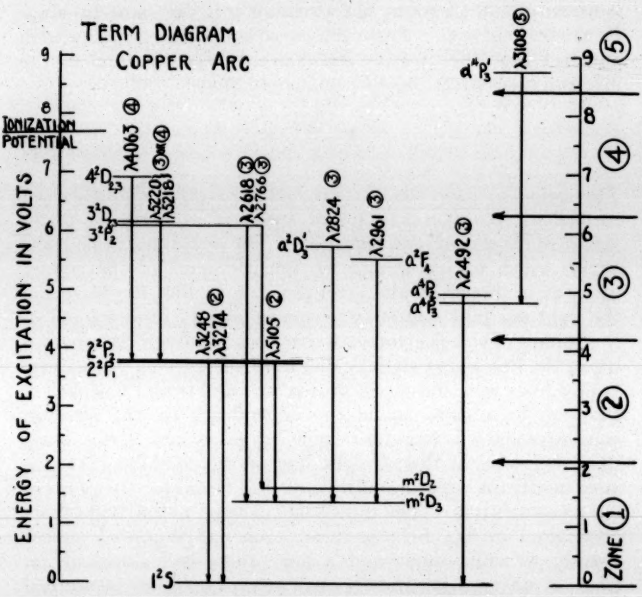
$$l = \frac{b^2}{c} n_-^2. \tag{15}$$

This equation expresses the fact that the light per unit volume emitted as radiation λ3274 *and* λ3248 *is proportional to the square of the electron concentration.* The next line studied was λ5105 which also originates in the 2^2P level of the copper atom as is shown by the level diagram in Fig. 6. Here too the light per unit volume was approximately proportional to the square of the electron concentration although the proximity of the line λ5153 slightly distorted the curve. Altogether twelve lines were measured in this way and from the slopes of the semi-logarithmic plots the dependence on the electron concentration was found for each. In every case it was found that the slope of the straight line of the semi-log plot was very nearly an integral multiple of that found for the positive ion concentration. The lines λ2961, λ2824, λ2766, and others designated in Fig. 6 by a three, each had slopes of almost exactly $3a$ while λ4063 and a few others had slopes of $4a$. Lines of wave-length shorter than λ2441 could not be studied because here the absorption of the light in the hot gas around the arc can not be neglected. Intensity measurements at λ2392 and λ2293 showed very little change when the arc current was changed as a result of this increased absorption.

Interpretation of results: These results can be easily explained if we assume that cumulative impacts of electrons on atoms are largely responsible for the excitation of the atoms. Let us imagine that there are certain discrete excitation energy levels in the atoms making up the gas of our arc discharge and designate these by 0, 1, 2, 3, etc. Let the difference in energy between consecutive states equal the average energy of the electrons. Assume that state "0" is the normal un-

excited state and that state "1" can be produced by a single impact of an electron with an energy equal to the average

FIG. 6.



Term diagram showing certain of the levels and lines of the copper arc spectrum.

energy of all the electrons. Within a unit volume the rate at which atoms enter or leave state "1" will be given

$$\frac{dN_1}{dt} = a_{01}N_0n - b_1N_1 - c_{12}N_1n. \qquad (16)$$

Here N_1 is the number of atoms per unit volume in state "1," n is the concentration of electrons, a_{01} is the constant of proportionality which when multiplied by N_0, the concentration of unexcited atoms, and n gives the rate at which atoms are excited to the state "1." The term $-b_1N_1$ represents the rate

at which atoms leave state "1" by a spontaneous giving up of energy in radiation. The term $-c_{12}N_1n$ gives the rate at which atoms leave state "1" to enter state "2" as a result of impacts with electrons. This rate certainly must be proportional to the concentrations N_1 and n with c_{12} as the constant of proportionality. In the steady state we must have $\frac{dN_1}{dt} = 0$ and therefore we can write

$$a_{01}N_0n - b_1N_1 - c_{12}N_1n = 0 \tag{17}$$

and in the same way we can write

$$c_{12}N_1n - b_2N_2 - c_{23}N_2n = 0, \tag{18}$$

$$c_{23}N_2n - b_3N_3 - c_{34}N_3n = 0. \tag{19}$$

These equations can be solved for N_1, N_2, etc., and we find

$$N_1 = \frac{a_{01}N_0}{b_1 + c_{12}n}\, n, \tag{20}$$

$$N_2 = \frac{a_{01}N_0c_{12}}{(b_1 + c_{12}n)(b_2 + c_{23}n)}\, n^2, \tag{21}$$

$$N_3 = \frac{a_{01}N_0c_{12}c_{23}}{(b_1 + c_{12}n)(b_2 + c_{23}n)(b_3 + c_{34}n)}\, n^3. \tag{22}$$

From these equations we see that the number of atoms in state "1" is proportional to the concentration of electrons; the number in state "2" is proportional to n^2 etc., if the number of atoms which leave a given state by radiating energy is large compared with those which leave it to enter a higher state due to electron impacts. We should therefore expect the intensity of light per unit volume which is given off the arc stream to be proportional to the square of the electron concentration if the atoms are each excited as result of two impacts of electrons. This theory is supported by the fact that the level diagram of Fig. 6 can be divided into "zones." Lines resulting from transitions originating in the second zone have intensities proportional to the square of the electron concentration, while those from the third zone are

proportional to the cube of the concentration and so on. It is important to note that the width of these zones, measured in volts, is about 2.1 volts and the average energy of the electrons as given by the probe measurements is also slightly greater than 2.1 volts. (See Fig. 4.)

GENERAL CONCLUSIONS.

These experiments have brought out a few simple facts concerning the mechanism of the electric arc which may be worth reviewing. The cathode fall in potential is usually equal to the ionization potential of the active gas but may, as in the case of the normal copper arc, be equal to the potential required to remove the second electron from an atom already singly ionized. The presence of a large concentration of singly or doubly charged atoms in the immediate neighborhood of the cathode surface is no doubt partly responsible for the high current density at the cathode. The electrons are found to have approximately a Maxwellian distribution of velocity with an average energy determined by critical potentials of the atom in case the gas or vapor playing the controlling part is monatomic. In case the gas is diatomic, as in the carbon arc in which we have the cyanogen molecule, the average energy of the electrons is not determined sharply and is not constant along the arc stream. This accounts for the "striations" found in the carbon arc.[1] The electrons produce the excitation responsible for the emission of light as a result of the cumulative action of successive impacts of electrons on atoms. It follows from this that the relative intensities of the lines observed in an electric arc are not fixed but depend on the current flowing because the concentration of electrons is a function of the current.

It is with pleasure that I acknowledge my indebtedness to Dr. W. F. G. Swann for many valuable suggestions.

MODULATION OF LIGHT WAVES.

BY

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BARTOL RESEARCH FOUNDATION
Communication No. 33.

WHEN light of a given frequency ν is passed through a dielectric, transparent to that frequency, which forms part of a parallel plate condenser, the light wave can be changed in character in two ways when electromagnetic waves of frequency P are impressed on the condenser.

First, the light, if it is initially plane polarized, will become elliptically polarized due to the medium becoming double refracting. If the frequency P of the electromagnetic waves is such that the medium has an absorption band at this frequency, then the double refraction will be considerable, or in other words, the Kerr constant will be abnormally large.

Second, the light train will be modulated, i.e., besides the original frequency ν, there will appear light trains of frequencies $\nu + P$, $\nu + 2P$, $\cdots$ and $\nu - P$, $\nu - 2P$, $\cdots$ etc. If the medium does not become double refracting, then the amplitudes of the modulated wave trains would be the same for corresponding frequencies, i.e., the amplitude of the light train of frequency $\nu - nP$ would be the same as that of frequency $\nu + nP$, so that the energy would be equally distributed towards the long and short wave-length side of the original line. When, however, account is taken of the double refraction of the medium, the energy will be no longer equally distributed among the modulated wave trains towards the long and the short wave-length side of the line, but there will be a greater amount of energy divided among the modulated waves on the long wave-length side of the line than towards the other side.

In these experiments, the light of an iron arc which passed through a Kerr cell containing water was photographed with a quartz spectrograph; the lines in the region from 2480 to 2500 Å. were examined with a microphotometer. It was found

that of the fifteen or more lines in this region only one showed any difference when the high frequency oscillations of wave-length, 8 meters approx., passed through the cell. This particular line at 2492.7 Å. was displaced towards the red by an amount .06 Å. On account of the complexity of the iron arc and the unknown structure of the lines, the mercury arc was substituted for it and the two lines at 2536.5 and 2534.7 Å. examined with a densitometer. The line at 2536.6 showed a shift towards the red with respect to the other line when the high frequency field was passing through the condenser. This effect was independent of the temperature of the water within the Kerr cell from 20° to 60° C., and independent also of the amount of the oscillatory current which passed through the cell but dependent on the wave-length of the high frequency waves. If the wave-length of the oscillations was changed from the value used in the above experiments, 8 meters approx., to 14 meters, the effect disappeared entirely. On varying the capacity of the system by small amounts, it was found that, as the frequency of the oscillations varied from one absorption band of the water to another, the effect reappeared and disappeared depending on whether the frequency of the electromagnetic waves was the same as or different from, that of the absorption frequency.

THEORY OF LIGHT MODULATIONS.

Before we discuss in detail the experimental results, we shall review the theory of light modulations which is based on Drude's theory of optically active media.

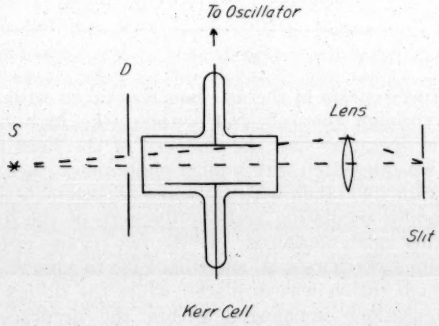
In the classical dispersion theory we suppose that when a light ray with electric vector E traverses a transparent medium it sets into motion the virtual oscillators which have a frequency characteristic of the medium, or expressed in different terms, it induces in the molecules of the medium a variable electric moment which emits secondary rays. If the frequency of the light train is ν and the frequency of the virtual oscillators is p, then besides wave trains of frequency ν, the primary radiation's frequency, there will appear wave trains of frequency $\nu - p$, $\nu - 2p \cdots \nu + p$, $\nu + 2p \cdots$, and the intensity of the wave trains of corresponding frequencies, i.e., the intensity of the rays of frequency $\nu - np$ and $\nu + np$ will

be in the ratio of $\left(\frac{\nu - np}{\nu + np}\right)^4$, which is essentially unity if the induced frequency $p << \nu$ (Carbannes 5. R. 186, p. 1714) so that the light intensity is equally divided among the long and short wave-length components of the line.

In the experiment we are describing we have a somewhat similar situation, except that here the induced electric moment of frequency p arises from the action of an electromagnetic field distinct from the primary light train; in this case, the external electromagnetic field acting on the medium was generated by the high frequency radio oscillator.

In the case considered by Carbannes, the secondary rays of frequency $\nu - p$, $\cdots$ are due to the interaction of the primary light wave of frequency ν and the secondary rays of frequency p emitted by the virtual oscillators. The phenomenon is here coherent, whereas in the other case where the radio waves cause the induced electric moment of the medium, the interaction of the induced moment and the primary light wave is non-coherent.

FIG. 1.

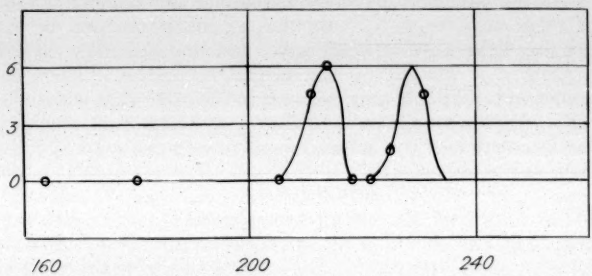


The diagram of the apparatus used to modulate the light is shown in Fig. 1. The light from the source S, in the first experiments with an iron arc, was passed through the Kerr cell, which contained water as the dielectric, and was then focused on the slit of the spectrograph by a quartz lens. The Kerr cell which had a capacity of 5 e.s.u., was the plate con-

denser of a high frequency oscillator which could oscillate at a wave-length as short as four meters. The diaphragm *D*, which was placed before the Kerr cell, allowed only the light which passed between the plates of that cell to enter the slit of the spectrograph.

On examining the spectrogram taken of the iron arc, it was found that several of the lines of the spectrum were displaced towards the red from their normal position when the light from the iron arc was photographed with the high frequency oscillations impressed on the cell. In order to measure this

FIG. 2.



shift, a spectrogram of the arc lines was taken with the light passing through the cell, but without the high frequency generator operating and the distance of the lines from one another was measured with a microphotometer, then a second spectrogram was taken with the same arrangement, but with the generator oscillating and the distance of the lines from one another again measured. In the two regions examined in detail from 2480 to 2500 Å. and from 2380 to 2400 Å. only one line in each region was displaced while the others retained their separations unchanged within the accuracy of the instrument, which was .01 Å. These two lines at 2498.9Å. and 2382 Å. respectively were displaced towards the red by .06 Å.

On account of the sensitiveness of the lines of the iron spectrum to external conditions and lack of information concerning the character of the spectrum, in the following experiments the mercury arc was used in place of the iron arc.

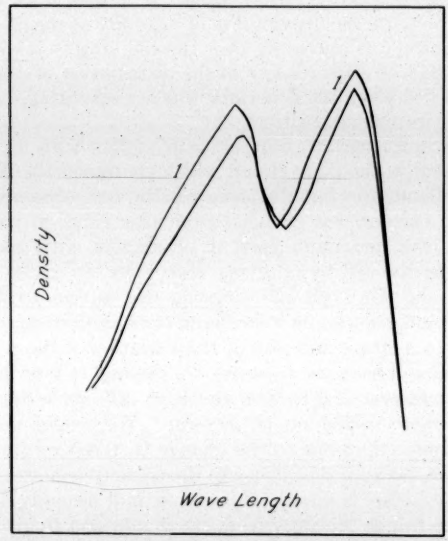
On examining the separation of the two mercury lines 2534.7 and 2536.5 Å., the latter showed a shift towards the red by the same amount as the iron lines, i.e., .06 Å. when the oscillations were passing through the cell. Fig. 2 shows the distribution of density for these two lines on the photographic plate, plotted against wave-length. It is seen from curve 1 which represents the distribution of intensity of the lines when the oscillator was operating that the line 2536.5 is displaced towards the red with respect to the distribution of density of the same line when the generator was not operating, i.e., with respect to its normal position.

These spectrograms were normally taken with an oscillatory current in the plate circuit which contained the Kerr cell of 3.0 milliamperes but the same results were obtained when the plate current was changed from this value to 9.0 milliamperes, the maximum current obtainable with the tube. On heating the cell by applying 1800 volts, 60 cycles, to the plates of the Kerr cell and allowing the current to flow for several hours, the results were found to be independent of this applied a.c. voltage and also of the variation of the temperature of the cell from 20° C. to 60° C., the higher limit being as far as it was practical to heat the Kerr cell, since the quartz windows were sealed on by cement. We would not have expected any effect due to the change in temperature of the water, first, because the change in the refractive index of water with temperature is small in this region, and secondly, because the source was so far away from the diaphragm *D*, see Fig. 1, that the light passing through the cell was practically parallel. These experiments show that any effect due to the change in the focusing of the light on the slit of the spectrograph is negligible. There existed the possibility, however, that the high frequency radiation from the generator might interact with the atoms emitting the light in the source. In order to test this possibility, the Kerr cell was removed from the path of the light beam. The spectrograms taken of the mercury arc in this way were the same whether the oscillator which was still connected to the Kerr cell was operating or not.

Finally the frequency of the system was changed by placing a variable air capacity in parallel or series with the Kerr

cell depending on the frequency change desired. Fig. 3 shows the change in separation of the lines from their normal separation when the oscillator is not acting as a function of the frequency of the oscillation.

FIG. 3.



The abscissæ represents the wave number $\times 10^{-6}$ of the radio frequency oscillations, the ordinates the frequency change of the line 2536.5 in unity of 1/100 Å. for these frequencies.

The curve in this figure, which shows the change in separation of the lines 2534.7 and 2536.5 plotted against frequency, shows a series of maxima and minima which correspond to the positions of the maxima and minima for the double refraction of light from the same frequency scale. (Kerr Effect in water for radio frequencies, J. FR. IN., Aug. 1928.) In that experiment the retardation of the elliptically polarized light produced by passing plane polarized light through a Kerr cell which was part of a high frequency oscillating circuit was measured for various frequencies of the oscillator. The

retardation was found to go through a series of maxima and minima as the frequency of the oscillations was changed. The retardation of the elliptically polarized light thus exhibited the same type of behavior as the displacement of the spectral lines. The two phenomena are also closely associated with the absorption bands for high frequency oscillations which correspond to the positions of the maxima of the retardation upon displacement of the spectral lines with regard to their frequency.

In conclusion, I wish to express my indebtedness to Professor James Barnes of Bryn Mawr College who kindly placed at my disposal his microphotometer and to the Department of Physics of Princeton University for allowing me the use of their high dispersion quartz spectrograph.

Crystallographic Study by X-Rays of the Structure of the Layer of Two Metals Deposited Simultaneously by Electrolysis. A. ROUX AND J. COURNOT. (*Comptes Rendus*, June 12, 1928.) Several pairs of metals were deposited together and the diffraction spectra of the resulting mixed layer were examined by X-rays to see whether each metal kept its personality or whether modifications occurred. The conclusion is "Examination of the results obtained show distinctly that the spectra of the deposits made simultaneously are not merely due to the superposition of the spectra of the constituent metals and consequently that during electrolysis the metals unite to form either solutions or combinations."

When copper and zinc were deposited together the strongest diffracted ray was obtained when the double angle of incidence was 21.46°. The strongest ray for copper was for the double angle of 22.29° while for zinc there were two strong rays for 18.03° and 21.20° respectively. The combined deposit seems to show no evidence of the two maxima displayed by zinc.

G. F. S.

Deviations from the Vertical in Corsica. P. HELBRONNER. (*Comptes Rendus*, June 25, 1928.) The work here reported was done in connection with the measurement of an arc of meridian. For the study of the effect of mountain masses in deviating a plumb line from its normal direction Corsica offers the advantage of being 100 km. from the mainland and of having within its borders quite high mountains. It is rather well isolated from distant gravitational attractions. At six stations on the island comparison was made between astronomical and geodesic latitude. The largest difference amounted to 61″, while the greatest divergence of the geodesic from the astronomical longitude was 64″. The deflecting forces acted in general toward the interior of the island in the direction of the nearest elevated masses, even when these seemed relatively unimportant in size and height. Any effect depending on geological formation was masked by the influence of altitude.

G. F. S.

THE HEAT CAPACITIES OF ORGANIC COMPOUNDS AT LOW TEMPERATURES. II. A LOW TEMPERATURE THERMOSTAT. THOUSANDTH DEGREE COPPER–CONSTANTAN THERMOCOUPLE REFERENCE TABLES FROM 85° TO 310° K.

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BARTOL RESEARCH FOUNDATION
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In connection with the work on the heat capacities of organic compounds described in paper I of this series [1] it was found necessary to obtain an improved temperature—e.m.f. scale for copper-constantan thermocouples in order that the specific heat measurements might have an accuracy of *one per mille;* that is to say, an absolute accuracy of 0.01° C. and a relative accuracy of at least 0.002° C. was required in the temperature measurements. Furthermore, it was desirable that this temperature scale should be based as directly as possible on the so-called International Temperature Scale of the University of Leiden, Reichsanstalt, and the U. S. Bureau of Standards. In order to accomplish this, it was necessary to devise a thermostat capable of maintaining the temperature constant to within 0.001° at any point from the boiling point of liquid air to room temperature. Moreover there seemed to be considerable general interest in devising a comparatively simple yet precise low-temperature thermostat. These considerations led to the research described herewith.

A comprehensive review of the work on low temperature thermostats up to 1925 is given by Walters and Loomis.[2] Maass and Barnes [3] have constructed an automatic thermostat

[1] D. H. Andrews, J. FRANKLIN INST., **206**, 285.
[2] Walters and Loomis, *J. A. C. S.*, **47**, 2302 (1925).
[3] Maass and Barnes, *J. A. C. S.*, **49**, 360.

accurate to 0.1°, and Simon [4] describes one accurate to several tenths of a degree. In addition to these an automatic thermostat with an accuracy of 0.01° was described in the first paper of this series.[5] However, this latter thermostat is so constructed that it is adaptable only to such work as can be carried on inside a steel vacuum bomb and the type of resistance thermometer in vogue at the present time at the Bureau of Standards cannot be completely enclosed in such a bomb. This fact led us to develop the following comparatively simple yet precise low temperature thermostat.

THE LOW TEMPERATURE THERMOSTAT.

The thermostat bath is of pentane contained in a cylindrical copper vessel (*C*, Fig. 1) with walls 2 mm. thick. A heating unit of 40 ohms resistance is wound around the outside of this vessel and the whole placed inside a small Pyrex Dewar flask (*B*) made for the purpose. All this in turn is placed in a bath of liquid air contained in a larger (quart) Dewar (*A*). The usual objection to this type of thermostat in the past has been the danger of the inner Dewar breaking and thus forming a highly explosive mixture of liquid air and pentane. This defect has been remedied by the use of the copper container.

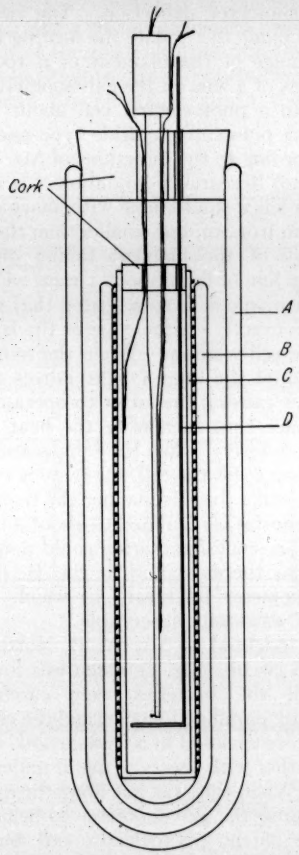
Thermal equilibrium is maintained to a fair degree by the heavy copper walls of the thermostat since it is of such dimensions that no point within it is more than 1.5 cm. from the walls. Sometimes a hand stirrer (*D*) is used but more often a heavy copper tube (not shown) of a diameter of about half that of the thermostat employed to further minimize temperature gradients. Obviously only the latter can be used below about 140° C. at which point pentane begins to solidify.

Temperature regulation is accomplished in the following way. A copper-constantan thermocouple is soldered to the inside of the copper container about one third of the way down from the top. The e.m.f. from this is opposed with that from a Type *K*, Leeds and Northrup potentiometer which can be set to correspond to the desired temperature. The thermo-

[4] Simon and col., *Ber.*, **60**, 568 (1927).

[5] *Loc. cit.*

FIG. 1.



couple and potentiometer are connected in series with a high sensitivity Leeds and Northrup galvanometer. Obviously when the temperature of the thermostat differs from that

corresponding to the e.m.f. set on the potentiometer there will be a galvanometer deflection. The deflection of the galvanometer is made to regulate the heating in the following manner. An image of the filament of a 100 watt lamp is focused by means of a lens on the galvanometer mirror which reflects this onto a photoelectric cell about ½ meter away. The cell is of the potassium hydride type and was made by the authors according to the directions of Mr. W. B. Nottingham of the Bartol Research Foundation. It is enclosed in a black box which has a square hole with sharp edges so placed that the hole is in front of, but smaller than the window in the cell. The image of the filament falling on the cell box produces a sharp line of light about 1 mm. wide and the zero point of the galvanometer is so adjusted that the edge of this line of light falls exactly on the edge of the square hole over the photoelectric cell window. When the temperature drops below that required the line of light moves about 0.2 mm. onto the cell thus causing the latter to operate a relay which shunts a resistance thus increasing the heat input into the thermostat. Conversely, when the temperature becomes too high the image moves off the cell, the relay is released and the heat input cut down. In this manner the temperature of the walls of the thermostat is regulated to about a thousandth of a degree. Even this small fluctuation could not be detected in the center of the thermostat with the B. of S. platinum resistance thermometer by means of which a temperature change of 0.001° was easily observable.

We are also indebted to Mr. W. B. Nottingham for the photoelectric cell circuit (Fig. 2) which was found to be very satisfactory. All the batteries were carefully insulated against grounds by paraffined blocks, and the cell, radio tubes, and grid leaks were enclosed in a lead covered moisture proof box. This, together with sheets of metal under the batteries, was grounded. When this was not done the operation of the cell seemed to cause the galvanometer to behave erratically. The adjustment of the photoelectric cell battery is quite critical as are also those of the other batteries to a lesser degree.

The thermostat heating circuit (Fig. 2) was so designed that the voltage drop across the heating coil and shuntable

resistance as well as the current through them could be adjusted. This was accomplished by placing directly across the 110 V., D.C. line a 65-ohm variable resistance and connecting one lead of the heater to the movable contact while the other was connected to one end of the resistance. It was necessary to have the resistance which the relay shunted

FIG. 2.

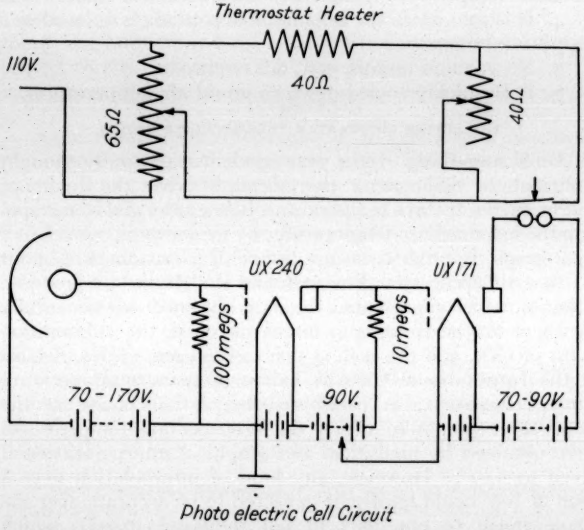


Photo electric Cell Circuit

variable in order that the change in heat with the operation of the cell could be adjusted to give the best temperature regulation.

In order to cool down the thermostat, the cork in the top of the outer Dewar is raised a short distance and liquid air blown in until its level is above that of the copper container, which is of such dimensions that it projects slightly above that of the Dewar which holds it. In this way the thermostat is quickly cooled and as soon as the slight excess of liquid air evaporates it is ready for use.

The advantages of this type of low temperature thermostat may be summed up as follows:

1. The temperature can be maintained constant to 0.001° for an indefinite length of time if proper stirring is provided.
2. Small quantities of liquid air are used. A day's work including cooling down, requires about two liters.
3. It requires only fifteen minutes to an hour to change from one temperature to another, and reëstablish equilibrium.
4. It is safe, since the inflammable pentane is encased in a copper container.
5. No vacuum pumps, etc., are required.
6. It is quickly cooled down to liquid air temperatures.

THE COPPER-CONSTANTAN THERMOCOUPLE TABLES.

Until something over a year ago it was generally thought sufficient to compare a thermocouple with the reference thermometer at three temperatures below zero, and to interpolate the intermediate temperatures by means of an equation or by a graph, in order to secure temperature readings of about 0.1 to 0.01° accuracy. Eastman and Rodebush [6] proposed an equation which represented the data obtained experimentally by them at the freezing point of mercury, the sublimation point of CO_2, and the boiling point of oxygen. Also, Adams in the International Critical Tables presents a temperature e.m.f. reference table based on observations made at the same three points in which the intermediate temperatures were obtained by analytical and graphical interpolation and given to 0.01°. However, any kind of interpolation over a span of 100° could hardly be expected to be accurate over the whole range to one part in ten thousand (0.01°), which precision we thought necessary for our work.

Recently Giauque, Buffington and Schulze [7] have compared a copper-constantan thermocouple at intervals of 10° from 25° to 283° K. with a hydrogen thermometer of their own construction and have presented a more or less empirical reference table from which they plot a deviation curve of one of their thermocouples. This deviation curve seems to be certain to only about 0.05° C., and weaves back and forth

[6] Eastman and Rodebush, *J. A. C. S.*, **40**, 489.
[7] Giauque, Buffington and Schulze, *J. A. C. S.*, **49**, 2343.

across the axis. It seemed to us desirable to have a reference table that is truly representative of the e.m.f. of an actual thermocouple so that a deviation curve such as would be necessary in using any other thermocouple would be regular, and could be obtained by making comparisons at say only 40° intervals. Also in order to reduce the labor of calculation the table should be extensive enough so that changes in the dE/dT and related quantities would be so small between tabulated temperatures that they could be neglected. Of course the table must have an absolute accuracy of 0.01° with respect to the International Temperature Scale.

EXPERIMENTAL.

As a comparison thermometer a Leeds and Northrup platinum resistance thermometer which had been calibrated by the Bureau of Standards, was used. This was checked before and after runs against another of the same type which had been calibrated by the Bureau of Standards less than a month before use. This last mentioned thermometer was reserved exclusively for checking purposes. In this way we made certain that no strains had developed during the experiments in the comparison thermometer, which would cause it to become faulty.[8]

Four thermocouples were calibrated, two being of constantan wire from one spool, and two from another, having a slightly different composition.[9] The wire was tested by drawing it through liquid air in the usual way and observing

[8] The "Comparison Thermometer" upon which the Standard Reference Tables are based is Leeds and Northrup Co.'s No. 128016 and B. and S. No. 2736, calibrated June 15, 1927. The "Checking Thermometer" with which the "Comparison Thermometer" was checked before and after each run is Leeds and Northrup Co.'s No. 137184, and B. and S. No. 312, calibrated November 5, 1928. These thermometers checked each other consistently, No. 128016 reading 0.002° higher than No. 137184 at −180° C.

It should be noted that the equation by which temperature is calculated for these thermometers expresses the result in ° C.; thus while our thermocouple readings are really based on the Centigrade scale, we have converted them to ° K., as the latter is the more useful scale for thermodynamic purposes. We have used the value 273.1° K. for the ice point and while the accuracy of this value seems to be in dispute, a change will merely mean adding a small constant correction to the tables.

[9] The wire is the so-called "ideal" wire made by the Driver-Harris Co.

e.m.f.'s due to nonuniformity. The thermocouples were bakelited to the case of the thermometer for practically its whole length in such a manner that their junctions lay about opposite the center of the thermometer coil and their leads had no turns or kinks in them. The thermometer was placed in the center of the thermostat bath as is shown in Fig. 1.

The resistance of the thermometer was easily observed to one ten-thousandth of an ohm by comparing it with a ten ohm coil calibrated by the Bureau of Standards. This was accomplished by connecting the two in series with rheostat and battery and comparing the potential drops across each of them by means of a White double potentiometer. The galvanometer was about 15 feet from the scale enabling the e.m.f. to be read to 0.1 μ V, and the thermometer to 0.001° with ease. The e.m.f. of the thermocouple was read on the same potentiometer.

Table I gives the experimental data from which the Standard Reference Tables have been calculated. Each point represents the average of from four to ten readings. Since the thermostat was constant to 0.001°, and the resistance thermometer could be read to the same fraction, the chief error was in reading the e.m.f. of the thermocouple. This was equivalent to from 0.002 to 0.006° depending on the part of the scale.

TABLE I.

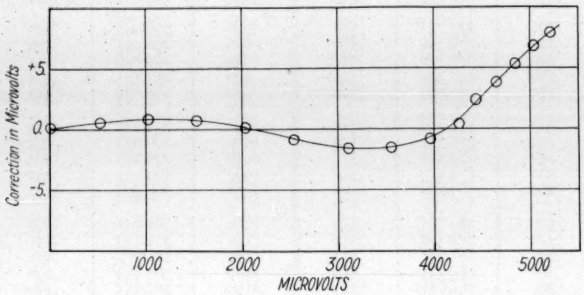
Temp. ° K.	E.M.F. in Microvolts.	Temp. ° K.	E.M.F. in Microvolts.
90.074	5216.6*	199.704	2541.7
90.186	5214.9	215.739	2033.2
99.890	5038.1	230.863	1529.2
109.786	4845.3	245.294	1026.5
119.225	4649.9	259.050	528.1
129.062	4434.0	273.1	0.2**
136.681	4259.6	285.757	− 489.9
149.151	3956.9	298.482	− 998.0
164.882	3548.2	311.170	− 1518.8
180.355	3117.9		

The reading marked (*) was taken in a bath of liquid oxygen. The one marked (**) was taken in a bath of finely crushed ice and distilled water such as is used for the ice junction. The fact that these readings fall on the curve with those taken in the thermostat is proof that there was no temperature gradient between the thermocouples and the resistance thermometer.

DERIVATION OF THE STANDARD REFERENCE TABLES.

The equation $E = E_0 - 0.447\ T^{1.699}$ was found to fit the above data approximately. E is the observed e.m.f., E_0 a constant, and T the temperature in degrees Kelvin. A deviation curve (Fig. 3) shows that excepting three points the maximum error is less than 0.1 μ V, which corresponds to 0.002 to 0.006°.

FIG. 3.



From this curve a correction was read and added algebraically to the above equation which was then solved for T. In this manner the temperature was calculated for every ten microvolts from 85° to 273.1° K. and every twenty microvolts from 273.1° to 310° K.

Temperature correction curves of the thermocouple made from wire of the second spool mentioned above were plotted from our table and from Adams's table. The corrections calculated from our table all lie on a perfectly smooth curve while some points calculated from Adams's lie as much as 0.04° off. The deviations of the data in Paper I treated in the same manner are about 0.01°. The e.m.f. of the thermocouple of Giauque is so radically different from that of ours that the corrections were too large to be plotted satisfactorily. Our original intention was to use the data in Paper I in conjunction with Adams's tables to establish the temperature scale. The above results show the advantage we have gained by means of the present investigation.

STANDARD REFERENCE TABLES FOR THE COPPER-CONSTANTAN THERMOCOUPLE.

Part I—Above 0° C.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
0	273.1		800	293.567	.499
20	273.624	.524	820	294.066	.499
40	274.148	.524	840	294.564	.498
60	274.672	.524	860	295.062	.498
80	275.195	.523	880	295.559	.497
100	275.717	.522	900	296.055	.496
120	276.239	.522	920	296.551	.496
140	276.760	.521	940	297.046	.495
160	277.280	.520	960	297.541	.495
180	277.800	.520	980	298.035	.494
200	278.319	.519	1000	298.529	.494
220	278.837	.518	1020	299.022	.493
240	279.354	.517	1040	299.515	.493
260	279.870	.516	1060	300.007	.492
280	280.385	.515	1080	300.499	.492
300	280.900	.515	1100	300.991	.492
320	281.414	.514	1120	301.482	.491
340	281.928	.514	1140	301.973	.491
360	282.441	.513	1160	302.463	.490
380	282.953	.512	1180	302.953	.490
400	283.465	.512	1200	303.442	.489
420	283.976	.511	1220	303.931	.489
440	284.487	.511	1240	304.419	.488
460	284.997	.510	1260	304.907	.488
480	285.496	.509	1280	305.394	.487
500	286.015	.509	1300	305.881	.487
520	286.523	.508	1320	306.367	.486
540	287.031	.508	1340	306.853	.486
560	287.538	.507	1360	307.338	.485
580	288.044	.506	1380	307.823	.485
600	288.549	.505	1400	308.307	.484
620	289.053	.504	1420	308.791	.484
640	289.557	.504	1440	309.274	.483
660	290.060	.503	1460	309.757	.483
680	290.563	.503	1480	310.239	.482
700	291.065	.502			
720	291.567	.502			
740	292.068	.501			
760	292.568	.500			
780	293.068	.500			

Part II—Below 0° C.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
0	273.1		450	261.163	.269
10	272.838	.262	460	260.893	.270
20	272.576	.262	470	260.623	.270
30	272.314	.262	480	260.353	.270
40	272.052	.262	490	260.083	.270
50	271.790	.262	500	259.813	.270
60	271.528	.262	510	259.542	.271
70	271.265	.263	520	259.271	.271
80	271.002	.263	530	259.000	.271
90	270.739	.263	540	258.729	.271
100	270.476	.263	550	258.458	.271
110	270.213	.263	560	258.187	.271
120	269.950	.263	570	257.915	.272
130	269.687	.263	580	257.643	.272
140	269.424	.263	590	257.372	.272
150	269.161	.263	600	257.099	.272
160	268.897	.264	610	256.827	.272
170	268.633	.264	620	256.554	.273
180	268.369	.264	630	256.281	.273
190	268.105	.264	640	256.008	.273
200	267.841	.264	650	255.735	.273
210	267.576	.265	660	255.462	.273
220	267.311	.265	670	255.188	.274
230	267.046	.265	680	254.914	.274
240	266.780	.266	690	254.640	.274
250	266.514	.266	700	254.366	.274
260	266.248	.266	710	254.091	.275
270	265.982	.266	720	253.816	.275
280	265.716	.266	730	253.541	.275
290	265.450	.266	740	253.266	.275
300	265.183	.267	750	252.991	.275
310	264.926	.267	760	252.715	.276
320	264.649	.267	770	252.439	.276
330	264.382	.267	780	252.163	.276
340	264.115	.267	790	251.887	.276
350	263.848	.267	800	251.610	.277
360	263.580	.268	810	251.333	.277
370	263.312	.268	820	251.056	.277
380	263.044	.268	830	250.779	.277
390	262.776	.268	840	250.502	.277
400	262.508	.268	850	250.225	.277
410	262.239	.269	860	249.947	.277
420	261.970	.269	870	249.669	.278
430	261.701	.269	880	249.391	.278
440	261.432	.269	890	249.113	.278

Part II—Below 0° C.—Continued.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
900	248.835	.278	1350	236.074	.289
910	248.556	.279	1360	235.785	.289
920	248.277	.279	1370	235.496	.289
930	247.998	.279	1380	235.207	.289
940	247.719	.279	1390	234.917	.290
950	247.440	.279	1400	234.627	.290
960	247.160	.280	1410	234.337	.290
970	246.880	.280	1420	234.047	.290
980	246.600	.280	1430	233.756	.291
990	246.320	.280	1440	233.465	.291
1000	246.040	.280	1450	233.174	.291
1010	245.759	.281	1460	232.883	.291
1020	245.478	.281	1470	232.592	.291
1030	245.197	.281	1480	232.300	.292
1040	244.915	.282	1490	232.008	.292
1050	244.633	.282	1500	231.716	.292
1060	244.351	.282	1510	231.424	.292
1070	244.069	.282	1520	231.131	.293
1080	243.787	.282	1530	230.838	.293
1090	243.504	.283	1540	230.545	.293
1100	243.221	.283	1550	230.251	.294
1110	242.938	.283	1560	229.957	.294
1120	242.655	.283	1570	229.663	.294
1130	242.372	.283	1580	229.338	.295
1140	242.088	.284	1590	229.073	.295
1150	241.804	.284	1600	228.778	.295
1160	241.520	.284	1610	228.483	.295
1170	241.235	.285	1620	228.187	.296
1180	240.950	.285	1630	227.891	.296
1190	240.665	.285	1640	227.595	.296
1200	240.380	.285	1650	227.299	.296
1210	240.095	.285	1660	227.002	.297
1220	239.909	.286	1670	226.705	.297
1230	239.523	.286	1680	226.408	.297
1240	239.237	.286	1690	226.110	.298
1250	238.951	.286	1700	225.812	.298
1260	238.675	.286	1710	225.514	.298
1270	238.378	.287	1720	225.216	.298
1280	238.091	.287	1730	224.918	.298
1290	237.804	.287	1740	224.619	.299
1300	237.516	.288	1750	224.320	.299
1310	237.228	.288	1760	224.021	.299
1320	236.940	.288	1770	223.722	.299
1330	236.652	.288	1780	223.422	.300
1340	236.363	.289	1790	233.122	.300

Part II—Below 0° C.—Continued.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
1800	222.822	.300	2250	209.010	.314
1810	222.522	.300	2260	208.696	.314
1820	222.221	.301	2270	208.382	.314
1830	221.920	.301	2280	208.067	.315
1840	221.619	.301	2290	207.752	.315
1850	221.317	.302	2300	207.437	.315
1860	221.015	.302	2310	207.121	.316
1870	220.713	.302	2320	206.805	.316
1880	220.410	.303	2330	206.488	.317
1890	220.107	.303	2340	206.171	.317
1900	219.804	.303	2350	205.854	.317
1910	219.501	.303	2360	205.537	.317
1920	219.197	.304	2370	205.219	.318
1930	218.893	.304	2380	204.901	.318
1940	218.589	.304	2390	204.582	.319
1950	218.285	.304	2400	204.263	.319
1960	217.980	.305	2410	203.944	.319
1970	217.675	.305	2420	203.624	.320
1980	217.370	.305	2430	203.304	.320
1990	217.064	.306	2440	202.983	.321
2000	216.758	.306	2450	202.662	.321
2010	216.452	.306	2460	202.344	.322
2020	216.145	.307	2470	202.022	.322
2030	215.838	.307	2480	201.700	.322
2040	215.531	.307	2490	201.377	.323
2050	215.224	.307	2500	201.054	.323
2060	214.917	.307	2510	200.731	.323
2070	214.609	.308	2520	200.408	.323
2080	214.301	.308	2530	200.084	.324
2090	213.992	.309	2540	199.760	.324
2100	213.683	.309	2550	199.436	.324
2110	213.374	.309	2560	199.111	.325
2120	213.064	.310	2570	198.786	.325
2130	212.754	.310	2580	198.461	.325
2140	212.444	.310	2590	198.135	.326
2150	212.133	.311	2600	197.809	.326
2160	211.822	.311	2610	197.483	.326
2170	211.511	.311	2620	197.156	.327
2180	211.199	.312	2630	196.829	.327
2190	210.887	.312	2640	196.501	.328
2200	210.575	.312	2650	196.173	.328
2210	210.263	.312	2660	195.845	.328
2220	209.950	.313	2670	195.516	.329
2230	209.637	.313	2680	195.186	.330
2240	209.324	.313	2690	194.856	.330

Part II—Below 0° C.—Continued.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
2700	194.526	.330	3150	179.236	.350
2710	194.195	.331	3160	178.885	.350
2720	193.864	.331	3170	178.534	.351
2730	193.532	.332	3180	178.182	.352
2740	193.200	.332	3190	177.830	.352
2750	192.868	.332	3200	177.477	.353
2760	192.536	.332	3210	177.124	.353
2770	192.203	.333	3220	176.770	.354
2780	191.870	.333	3230	176.416	.354
2790	191.536	.334	3240	176.062	.354
2800	191.202	.334	3250	175.707	.355
2810	190.868	.334	3260	175.352	.355
2820	190.533	.335	3270	174.996	.356
2830	190.198	.335	3280	174.640	.356
2840	189.862	.336	3290	174.283	.357
2850	189.526	.336	3300	173.936	.357
2860	189.190	.336	3310	173.568	.358
2870	188.853	.337	3320	173.210	.358
2880	188.516	.337	3330	172.851	.359
2890	188.178	.338	3340	172.491	.360
2900	187.840	.338	3350	172.131	.360
2910	187.501	.339	3360	171.770	.361
2920	187.161	.340	3370	171.409	.361
2930	186.821	.340	3380	171.047	.362
2940	186.480	.341	3390	170.685	.362
2950	186.139	.341	3400	170.322	.363
2960	185.798	.341	3410	169.958	.364
2970	185.456	.342	3420	169.594	.364
2980	185.114	.342	3430	169.230	.364
2990	184.772	.342	3440	168.865	.365
3000	184.430	.342	3450	168.499	.366
3010	184.087	.343	3460	168.133	.366
3020	183.744	.343	3470	167.766	.367
3030	183.400	.344	3480	167.399	.367
3040	183.055	.345	3490	167.031	.368
3050	182.710	.345	3500	166.662	.369
3060	182.364	.346	3510	166.293	.369
3070	182.018	.346	3520	165.924	.369
3080	181.672	.346	3530	165.554	.370
3090	181.325	.347	3540	165.183	.371
3100	180.978	.347	3550	164.812	.371
3110	180.631	.347	3560	164.440	.372
3120	180.283	.348	3570	164.067	.373
3130	179.834	.349	3580	163.693	.374
3140	179.585	.349	3590	163.319	.374

Part II—Below 0° C.—Continued.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K	Diff.
3600	162.944	.375	4050	145.393	.407
3610	162.569	.375	4060	144.985	.408
3620	162.193	.375	4070	144.576	.409
3630	161.818	.376	4080	144.167	.409
3640	161.442	.376	4090	143.757	.410
3650	161.065	.377	4100	143.346	.411
3660	160.687	.378	4110	142.934	.412
3670	160.308	.379	4120	142.521	.413
3680	159.928	.380	4130	142.107	.414
3690	159.548	.380	4140	141.692	.415
3700	159.167	.381	4150	141.276	.416
3710	158.786	.381	4160	140.859	.417
3720	158.404	.382	4170	140.441	.418
3730	158.021	.383	4180	140.022	.419
3740	157.677	.384	4190	139.602	.420
3750	157.255	.384	4200	139.181	.421
3760	156.868	.385	4210	138.759	.422
3770	156.483	.385	4220	138.337	.422
3780	156.097	.386	4230	137.914	.423
3790	155.710	.387	4240	137.490	.424
3800	155.323	.387	4250	137.066	.424
3810	154.935	.388	4260	136.641	.425
3820	154.546	.389	4270	136.215	.426
3830	154.157	.389	4280	135.788	.427
3840	153.767	.390	4290	135.360	.428
3850	153.376	.391	4300	134.931	.429
3860	152.984	.392	4310	134.500	.431
3870	152.592	.392	4320	134.068	.432
3880	152.199	.393	4330	133.635	.433
3890	151.806	.393	4340	133.201	.434
3900	151.402	.394	4350	132.766	.435
3910	151.008	.394	4360	132.330	.436
3920	150.613	.395	4370	131.893	.437
3930	150.017	.396	4380	131.555	.438
3940	149.821	.396	4390	131.016	.439
3950	149.424	.397	4400	130.576	.440
3960	149.026	.398	4410	130.135	.441
3970	148.627	.399	4420	129.693	.442
3980	148.226	.401	4430	129.250	.443
3990	147.824	.402	4440	128.806	.444
4000	147.421	.403	4450	128.361	.445
4010	147.017	.404	4460	127.915	.446
4020	146.612	.405	4470	127.468	.447
4030	146.206	.406	4480	127.020	.448
4040	145.800	.406	4490	126.571	.449

Part II—Below 0° C.—Continued.

E.M.F.	Temp. ° K.	Diff.	E.M.F.	Temp. ° K.	Diff.
4500	126.121	.450	4900	107.044	.505
4510	125.670	.451	4910	106.537	.507
4520	125.217	.453	4920	106.028	.509
4530	124.763	.454	4930	105.517	.511
4540	124.308	.455	4940	105.004	.513
4550	123.852	.456	4950	104.490	.514
4560	123.394	.458	4960	103.974	.516
4570	122.935	.459	4970	103.456	.518
4580	122.475	.460	4980	102.937	.519
4590	122.014	.461	4990	102.416	.521
4600	121.551	.463	5000	101.894	.522
4610	121.087	.464	5010	101.370	.524
4620	120.621	.466	5020	100.835	.525
4630	120.154	.467	5030	100.308	.527
4640	119.686	.468	5040	99.780	.528
4650	119.217	.469	5050	99.250	.530
4660	118.747	.470	5060	98.719	.531
4670	118.276	.471	5070	98.186	.533
4680	117.804	.472	5080	97.651	.535
4690	117.331	.473	5090	97.113	.538
4700	116.856	.475	5100	96.573	.540
4710	116.380	.476	5110	96.030	.543
4720	115.902	.478	5120	95.484	.546
4730	115.422	.480	5130	94.935	.549
4740	114.940	.482	5140	94.383	.552
4750	114.457	.483	5150	93.829	.554
4760	113.973	.484	5160	93.273	.556
4770	113.488	.485	5170	92.715	.558
4780	113.001	.487	5180	92.155	.560
4790	112.513	.488	5190	91.593	.562
4800	112.023	.490	5200	91.029	.564
4810	111.532	.491	5210	90.463	.566
4820	111.039	.493	5220	89.895	.568
4830	110.545	.494	5230	89.325	.570
4840	110.049	.496	5240	88.753	.572
4850	109.552	.497	5250	88.178	.575
4860	109.054	.498	5260	87.600	.578
4870	108.554	.500	5270	87.020	.580
4880	108.052	.502	5280	86.438	.582
4890	107.549	.503	5290	85.853	.585

EFFECT OF TEMPERATURE GRADIENTS.

Giauque, Buffington and Schulze [10] suggest that the irreversible heat flow which is necessarily present in thermo-

[10] *Loc. cit.*

couples may be contributing appreciably to the e.m.f. and if so the amount due to this factor may depend on the character of the gradient. To investigate this a piece of constantan wire was tested by drawing it through liquid air in the usual manner and a portion selected which did not cause a galvanometer deflection corresponding to more than one μV. Without removing the wire from the bath two copper strips $1\frac{1}{2}''$ wide and $2\frac{1}{2}'$ long were clamped on the wire and dipped into the liquid air. This distributed the temperature difference of about 300° over a distance of two feet on one end of the wire while on the other end there was the same temperature difference in a few inches. If temperature gradient affected the e.m.f. noticeably the absolute e.m.f. in the latter case would be different from that observed with equal temperature gradients on either end. No change was observed and furthermore pulling the wire carefully through the copper strips in the latter case did not cause a galvanometer deflection corresponding to more than was observed without them namely, $1\ \mu\ V$. The experiment was repeated with a different piece of wire and the same results were obtained. Hence it is concluded that the temperature gradient per unit length between the "hot" and "cold" junctions of thermocouples does not affect the e.m.f. noticeably *provided* the wire is homogeneous.

The authors wish to express their appreciation to Mr. R. F Deese for the very helpful assistance which he gave them in making the measurements. The authors are also deeply indebted to Mr. W. B. Nottingham for his advice on the photoelectric equipment which played such a vital part in bringing about the success of the project.

Intense Ionization of the Air in Localities often Struck by Lightning. C. DAUZÈRE AND J. BOUGET. (*Comptes Rendus*, June 18, 1928.) In a previous paper the authors advanced the idea that the predilection of lightning for certain places depends upon geological constitution and that there may be a greater ionization of the air in such places than in others less visited by lightning. They now proceed to test their hypothesis by experiment. Using an Elster and Geitel apparatus they recorded the time required for the charge to leak away so that the potential of the cylinder sank from one value to another. From this was calculated the conductivity of the air due to ions opposite in sign to the charge of the cylinder. In strictness ions of both signs should be taken into account but simple apparatus was essential since the observations were conducted in the Pyrenees under difficult conditions. The experiments were uniformly carried out at a distance of 15 cm. above the surface of the earth. Quiet weather was preferred, but measurements were made also just before storms. It was sought to make the observations at places of the same altitude and not far apart and also with short intervals of time intervening. In one case there was immediately before a heavy rain a conductivity of 1.24×10^{-4} electrostatic units at a place where lightning fell whereas it was only about 70% as much at a point 200 m. southeast of the first or at a point at the same distance northeast of the first. The investigators examined many places and found conditions analogous to those just cited. They draw the conclusion that "there are places where the ionization of the air near the ground is constantly more intense than at neighboring places at the same altitude and under the same physical conditions. The spots frequently struck by lightning coincide with the places of maximum ionization. Their position depends on the geological composition of the ground." When a storm comes the ascending current of air carries up ions from the place near the earth where they have been produced in the greatest numbers. Thus there is a somewhat vertical column of ions that acts like a lightning rod in attracting the discharge and providing it with a path of small resistance.

Places of intense ionization will assist the leakage from transmission lines, influence the progress of thunder storms and have some connection with atmospherics in radio transmission. The electrometer can render further aid in furnishing information relating to the composition of the geological strata beneath. It seems possible that the electrometer for the measurement of ionization at the surface of the earth may associate itself with the other physical instruments that furnish information of the inaccessible parts of the earth. G. F. S.

THE MEASUREMENT OF SOUND ABSORPTION COEFFICIENTS.*

BY

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INTEREST in quantitative data on the absorption of sound by materials arises almost wholly in connection with the problems of architectural acoustics. In the thirty years that have elapsed since the pioneer work in this field by Professor Wallace C. Sabine, it has come to be almost universally recognized that reverberation is by far the most important factor affecting hearing conditions within rooms. The control of reverberation lies in providing the proper areas of sound absorbent surface of known absorbing efficiency. The determination of the relative efficiencies of various materials used for this purpose becomes thus a matter of considerable practical importance.

At the present time there is rather a wide divergence in the values of the "absorption coefficients" obtained by measurements on the same materials by different observers, using in some instances the same, and in other instances different, methods. Apart from the intrinsic difficulties of sound measurements in general, and the consequent lack of precision in such measurements, it appears that there are also hitherto unrecognized factors that affect the measured values of sound absorption coefficients of materials, the neglect of which doubtless accounts for much of this difference of results. A careful study of all the factors that affect these measured values is therefore of importance both for scientific and practical reasons.

From time to time during the last nine years, investigations of various aspects of this problem have been made at the Riverbank Laboratories. Within the last year, more in tensive work has been done, and some of the results are here presented with the hope that the reason for the differences just mentioned may appear, and that a fuller knowledge of

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the various factors involved may lead to a somewhat more standardized practice in carrying out laboratory measurements of sound absorption coefficients.

THEORY OF THE REVERBERATION METHOD.[1]

For the sake of definiteness in discussion, let us assume within a room of volume V, a source of sound whose acoustic output is E ergs per second. The rate of change of the average sound intensity due to absorption at the bounding surfaces of the room is given by the equation

$$\frac{dI}{dt} = -AI, \tag{1}$$

I being expressed in ergs per cubic meter. Then the rate of change of energy density in the room with the source speaking is

$$\frac{E}{V} - AI = \frac{dI}{dt}. \tag{2}$$

In the steady state, in which production at the source is just balanced by dissipation at the boundaries, the intensity I_0 is given by the expression

$$I_0 = \frac{E}{AV}. \tag{3}$$

Suppose the source is sounded for a time sufficiently great that the steady state is practically reached, and then suddenly stopped, and that the time, t, is measured from this instant. Integrating (1) and supplying the constant $I = I_0 = E/VA$, when $t = 0$, we have

$$At = \log_e \frac{I_0}{I} = \log_e \left(\frac{E}{VAI} \right).$$

If t_1 is the time required for the energy density to decrease to i, the threshold of audibility, then

$$At_1 = \log_e \left(\frac{E}{VAi} \right). \tag{4}$$

[1] Throughout the discussion, the nomenclature is that given by Wallace Sabine. The analysis follows that given by Franklin, Jaeger, Eckhardt and Buckingham.

We may express equation (4) in terms of what has been called the "total absorbing power" of the room and defined by the expression

$$a = \Sigma a_1 s_1 + a_2 s_2 + a_3 s_3 + \text{etc.}, \tag{5}$$

in which s_1 is the area in square meters of the surface whose *absorption coefficient* is a_1, the summation being extended to include all the surfaces in the room at which sound is reflected. If S is the total surface, a/S is the mean absorption coefficient. The average number of reflections per second is v/p, v being the velocity and p the mean free path of any "soundelement" between reflections. By methods of the kinetic theory, p has been shown to be $4V/S$, so that

$$A = \frac{v}{p} \cdot \frac{a}{S} = \frac{av}{4V}. \tag{6}$$

Equation (4) thus becomes

$$at_1 = \frac{4V}{v} \log_e \left(\frac{4E}{avi} \right) = 9.2 \frac{V}{v} \left(\log_{10} \frac{4E}{avi} \right). \tag{7}$$

Certain assumptions are involved in the derivation of the foregoing. Some of these have been set forth in an excellent critical paper on the subject by Dr. Edgar Buckingham.[2] Since the discrepancies in experimental results may be in part due to the doubtful validity of some of these assumptions, it may be well to state them explicitly:

1. It is assumed that E, the acoustic energy generated per second at the source is constant and is not influenced by the reaction of the standing wave system in the room.

2. In the steady state, the sound energy in the room is uniformly distributed in space, and is diffuse as regards direction of propagation. This assumption ignores the inequalities of energy distribution due to interference.

3. The level of the steady state intensity is that at which the rate of emission of acoustic energy from the source is equal to the rate of absorption at the bounding surfaces.

4. The time rate of change of intensity at any instant due

[2] "Theory and Interpretation of Experiments on the Transmission of Sound through Partition Walls," Sci. Paper, Bur. of Strand. 506.

to absorption is strictly proportional to the intensity at that instant.

5. At any given surface, a certain fraction of the energy is absorbed at each reflection of sound from that surface. This fraction, the absorption coefficient, is constant for a pure tone of given pitch, and is not a function of intensity. It may or may not be a function of the angle of incidence. It is only assumed that as a function of the angle of incidence it has a mean statistical value for sound incident at the random angle of incidence assumed in the theory.

6. The contribution to the total absorbing power of the room by any surface is the product of the area and the absorption coefficient of that surface. This assumes that the actual energy absorbed per unit area is uniform over the entire surface. It follows from these assumptions that duration of audible sound after the source has ceased should be independent of the position of the source in the room, and that the energy absorbed by a given surface is independent of the position of the surface.

7. The dissipation of sound energy in the atmosphere, due to the viscosity of the air itself, is negligibly small in comparison with the dissipation at the boundaries of the room.

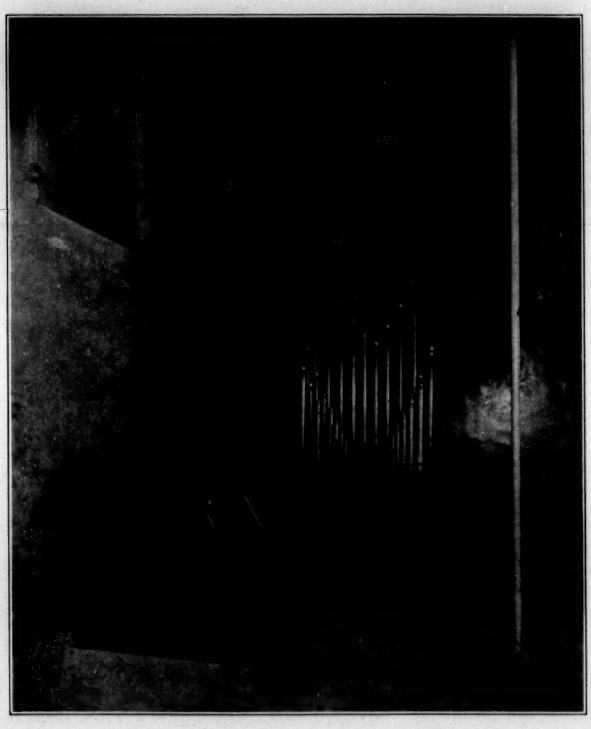
Turning now to the implications of equation (7): (1) It is apparent that the actual time t_1 as measured by any observer for sound from a given source will vary linearly with the logarithm of the acoustic power of the source; (2) that all other conditions being constant, the measured reverberation time is a linear function of the logarithm of the sensitivity (reciprocal of the threshold intensity) of the ear of the observer. (3) Knowing a, for any given room, equation (7) affords a means of evaluating E/i for any given constant source of sound and any observer, from the observed reverberation time. From this, one may plot a as a function of t, for the given room, source, and observer. From such a curve the total absorbing power of the room when altered by the introduction of absorbing material is known by observation of the reverberation time in the altered room.

APPLICATION OF THE METHOD.

The Sound Chamber.

Figure 1 gives a view of the Sound Chamber of the Riverbank Laboratories. As sources of sound, a set of 73 open

FIG. 1.

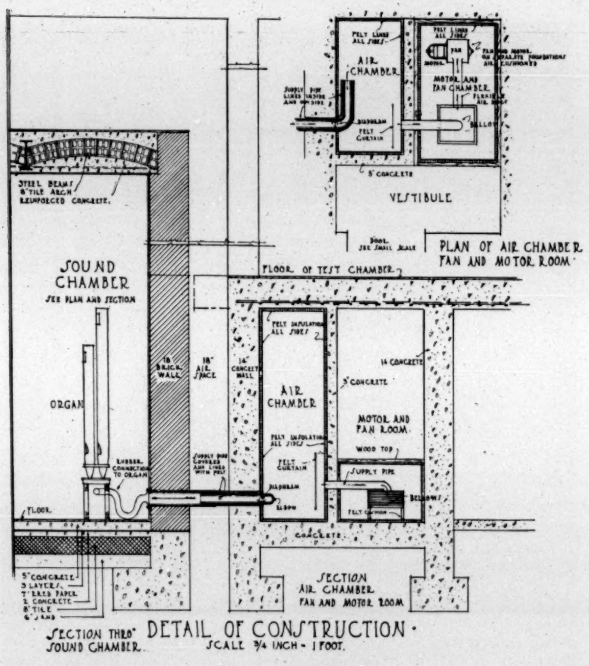


View of Sound Chamber.

diapason organ pipes ranging in pitch from 64 to 4,096 vibrations per second is employed. Air pressure for blowing these

pipes is supplied by means of an organ blower located outside the Sound Chamber. Figure 2 shows in plan and section the arrangement by which the noise of the blower is prevented from passing through the air passage into the Sound Chamber.

FIG. 2.



Detail showing Sound Insulation between Blower Room and Sound Chamber

The dimensions of the room are 8.25 x 5.80 x 6.05 meters, giving a volume of 289 cubic meters. From this a deduction of 3 cubic meters is made for the observer's cabinet and the organ, giving an effective volume of 286 cubic meters. Large steel reflectors, mounted on a vertical axis in the center of the

room and extending through the ceiling, are rotated noiselessly at the rate of 1 revolution in two minutes, for the purpose of constantly shifting the standing wave system during the course of the measurements. The walls are of brick, 18″ thick, plastered and finished with hard plaster, and painted with enamel paint.

During the course of the observations, the observer is seated in a wooden cabinet with only his head exposed. This cabinet is mounted on rollers, and a standard set of observations includes five observations for each tone, with the observer's cabinet in each of five standard positions—twenty-five observations in all. Due to the fact that the Sound Chamber is partially below ground and is not heated directly by artificial means, the temperature is fairly constant—58° to 68° F. the year round. The acoustic conditions in the room remain fairly constant. Thus for the tone C_4, 512 vibs./sec., the mean of twenty sets of observations taken by one observer over a period of six years, and selected at random from the notes covering the period was 14.36 seconds with a maximum deviation from the mean of. 6 secs. and an average deviation of .31 secs. The room is naturally sensitive to slight changes of absorbing power. The presence of a single person in the room outside the cabinet will lower the reverberation time at C_4 approximately 1.5 seconds. Changes in the relative humidity produce a marked effect upon the dissipation of sound of frequencies higher than 2,000 vibs./sec. Lowering the relative humidity increases the rate of absorption. No adequate explanation has yet been found for this phenomenon.

Three openings, one 1.83 x 2.44 meters, the other two .91 x 2.44 meters, are provided with solid steel doors. Test samples can be mounted on partitions built into these openings, so that by closing these doors, the Sound Chamber is reduced to its standard conditions. Portable samples are carried into the Sound Chamber and laid on the floor for tests.

The actual procedure in the measurement of absorption coefficients of a material is as follows: With the observer's cabinet in one of the five positions, a set of five observations of the time of reverberation for each of the test tones used is made, with the room in its standard condition. Immediately afterwards, the room is modified exposing test sample and the

set of observations is repeated. The observer's cabinet is moved, and the two sets of observations are repeated, in the reverse order. Alternating in this way, to eliminate any possible effects of fatigue, the reverberation times for the two conditions with the observer in each of the five positions in turn are measured. It may be said that effects of ear fatigue as shown by reduced times are seldom observed, except after prolonged work of this kind. The change in absorbing power of the room due to the introduction of the test panels is computed from the measured reverberation times by means of equation (7).

Calibration of the Sound Chamber.

The use of equation (7) necessitates first the evaluation by some means of a, the total absorbing power of the Sound Chamber in its standard condition, or of E/i for a given source and observer. Given a, $\log E/i$ for any given source and observer, is determined directly by the equation and the observed value of t_1, which being known, enables us in turn to compute a', the absorbing power for the observed value of the time under any other condition of the room. An alternative method of evaluating a is by means of a sound source whose acoustic output can be varied in known ratios. Let t_1 = time for a source of output E_1 and t_2 = time for an output E_2. Then

$$a = \frac{9.2\,V}{v}\left(\frac{\log E_1/E_2}{t_1 - t_2}\right). \tag{8}$$

This method of determining absolutely the total sound absorbing power of a room is originally due to Wallace Sabine in what he called the "Four Organ Pipe Experiment." Reverberation times with one, two, three, and four organ pipes in turn were determined. The total acoustic output of the four pipes was assumed to be four times that of one pipe. The value of a was thus determined for the large lecture room of the Jefferson Physical Laboratory for each of the seven C's from 64 to 4,096 vibs./sec. In his subsequent work, the rates of emission of his organ pipes were measured in terms of his own threshold of hearing by timing in this particular room.[3]

[3] It is worth noting in passing that the method here outlined is not based upon an assumed absorption coefficient of unity for an "open window," and that

It was assumed that these pipes when blown at the same pressure in another room would emit sound at the same rate, and thus afford a means of determining the total absorbing power of the second room. This method of calibration was employed for the Constant Temperature room at Harvard, in which most of Professor Sabine's measurements of absorption coefficients were made.

This method was employed in the original calibration of the Sound Chamber in this laboratory. With the view of making this calibration, two sets of open diapason pipes had been timed by Professor Sabine and by his assistant, Mr. John Connors, in the large lecture room of Jefferson Laboratory. The times for these same pipes by the same observers, in the new Sound Chamber were to be used in determining its absorbing power, to serve as the basis of future work here. Unfortunately the chain of complete continuity with the earlier work at Harvard was broken by Professor Sabine's untimely death in January, 1919. In taking up the work here, the two sets of pipes for which the acoustic outputs in terms of Professor Sabine's threshold intensity were known, were used in determining the absorbing power of the Riverbank Sound Chamber. This procedure neglected the difference that may exist in the values of the threshold intensities for normal hearing persons. At the time, the fact that this variation is appreciable had not been established. Fortunately, the form of the reverberation equation, involving as it does the logarithm of the absolute sensitivity, is such that only rather extreme variations in the sensitivity of the observer's hearing will effect any marked difference in the measured values of absorption coefficients. Thus under the experimental conditions prevailing here, if a variation in sensitivity by a factor of 10 between two observers be ignored, the difference in the absorption coefficient of a given material as computed from careful observation by the two will differ by about 10 per cent. of itself.

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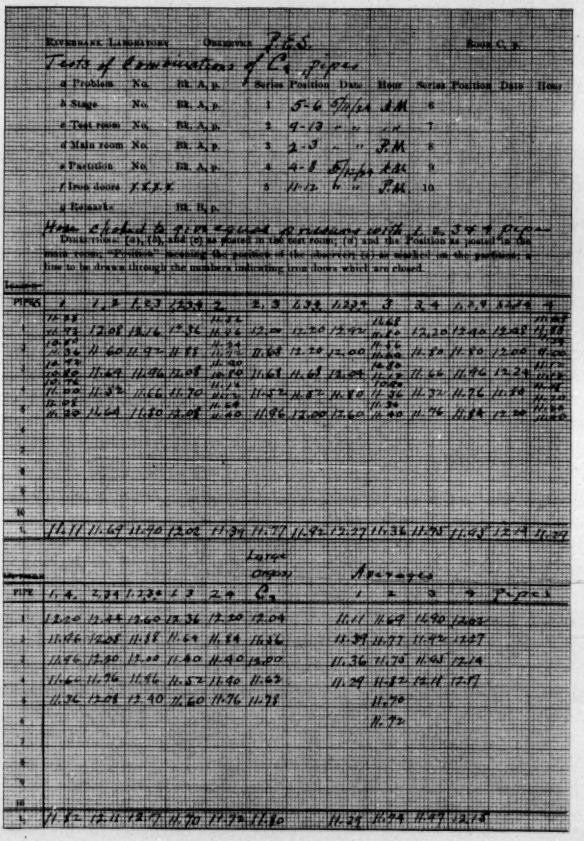
the coefficients given in Sabine's later papers are not determined on this assumption. As will appear later, the phenomenon of diffraction complicates the passage of sound out through an opening, so that it is only under special conditions as to size and dimensions that an open window may be treated as an ideal absorber with a coefficient of unity.

FIG. 3.



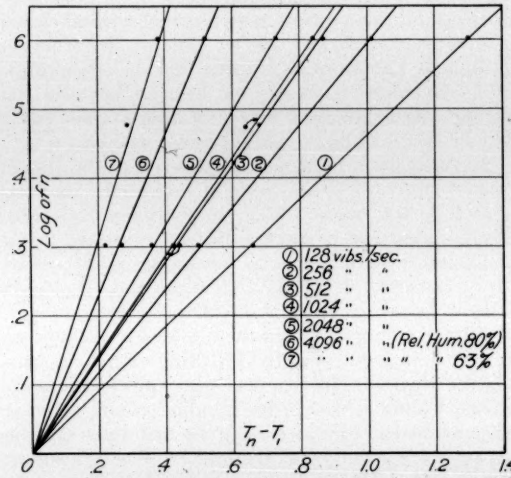
Sample data sheet for Four Organ Calibration.

Comparison of timings by the writer and by Mr. Connors under the same conditions in the Constant Temperature room at Harvard, in 1919, gave no evidence of a marked difference in sensitivity. so that professor Sabine's values of E/i for the two sets of pipes were adopted and the absorbing power of the Sound Chamber for the seven tones at octave intervals from 64 to 4,096 vibs./sec. was determined.

The work on the absolute sensitivity of normal ears, done in this laboratory by Kranz, and by Fletcher and others at the Bell Telephone Laboratories, showed that the assumption of a negligible difference in acuity of hearing between normal hearing persons might be a source of appreciable error, particularly in a room of low absorbing power and long reverberation. Accordingly in 1925, an independent calibration of the total absorbing power of the Sound Chamber by the multiple source method was made. Four small organs, each provided with six C pipes, 128 to 4,096 vibs./sec., were set up in the Sound Chamber with a special keyboard in the observer's cabinet by means of which the four pipes of each pitch could be made to speak singly and in all possible combinations. Air pressure was supplied from the blower for the large organ, the pressure being controlled by throttling so that the speaking pressure was the same whether one or four pipes were speaking. The Sound Chamber was in its standard condition, save for the presence of the four small organs and their equipment. The organs were arranged at the four corners of a square 2.8 meters on a side. The steel reflectors were kept moving during the measurements. Each combination for each pitch was timed with the observer in each of the five standard positions. The four pipes were carefully timed to unison before each set of observations. Preliminary experiments showed that only a slight difference in pitch between the pipes of a given combination produced a marked difference in the measured reverberation time. Figure 3 shows a typical data sheet. Each numerical value represents the mean of five separate observations, giving a total of 575 timings. Obviously, the method calls for a large number of observations made under carefully controlled conditions, in order to give even a fair degree of precision in the results. Three sets of determinations similar to that shown were made for the tone C_4, to establish the linear

relation between the difference in time and the logarithm of the number of pipes, and from that experience it appeared that a better procedure for the remaining pipes was to concentrate on the timings of one, four, and all the combinations of two pipes. In Fig. 4 the data for the six tones are plotted.

FIG. 4.



Increase in Reverberation Time vs. the logarithm of the number of pipes speaking

At the end of the experiment, using the pipes calibrated at Harvard by Professor Sabine, reverberation times first with the four organ pipe apparatus in, and then out of, the room were carefully determined, in order to calculate the value of the total absorbing power of the Sound Chamber in its standard condition. In Table 1, T and T', a and a', give values of these times and the corresponding absorbing powers without, and with, the four organs in the room. a' is determined from the slopes of the lines shown in Fig. 4-a is computed by the equation

$$a = \frac{7.70}{t}\left(\frac{\log 4E}{a'vi}\log - t'/t\right). \tag{8}$$

In the columns headed "W.C.S." the corresponding values as computed from Professor Sabine's values of E/i are shown. In view of all the circumstances, the agreement is probably as close as could be expected.

TABLE I.

Sound Chamber Calibration, Four Organ Pipe Method.

Tone.	T	T'	a'	a		$\log E/i$		Diff.
				P.E.S.	W.C.S.	P.E.S.	W.C.S.	
C_2	14.70	12.58	3.56	3.09	3.44	8.31	8.85	−10%
C_3	14.50	12.42	4.67	4.03	3.71	10.14	9.33	+8.6%
C_4	14.25	11.94	5.38	4.55	4.17	11.01	10.09	+8.9%
C_5	12.80	11.32	5.58	4.98	4.73	10.91	10.28	+5.3%
C_6	9.86	9.16	6.34	5.92	5.86	10.27	10.05	+1.0%
[1]C_7	5.63	5.29	8.90	8.40	7.83	8.98	8.60	+4.0%
[2]C_7		4.86	12.2			8.84		

[1] Relative humidity 80 per cent.
[2] Relative humidity 63 per cent.

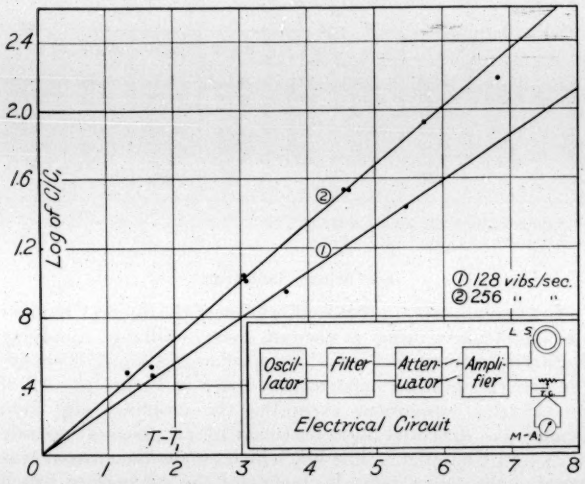
Loud Speaker Calibration.

In October, 1927, a third calibration of the Sound Chamber was undertaken using a vacuum tube oscillator supplying alternating current to a radio loud speaker as a source of sound. The experimental arrangement is shown in Figure 5. All of the electrical apparatus excepting the amplifier and loud speaker was operated and controlled by an assistant outside the Sound Chamber. The key which breaks the current was operated through a relay by means of the mechanism which starts the stop-watch timer. The loud speaker was of the moving coil, free-edge-cone type. The thermo-couple with its shunts was in series with the moving coil. The thermocouple and micro-ammeter with the various shunts used were calibrated with direct current meters for a current range of 0.4 to 250 mil-amperes. For each tone, a low pass electrical filter with a cut-off frequency lower than the first harmonic of the test-tone was used, thus giving a sinusoidal current supply to the loud speaker.

In Figs. 5 and 6, the logarithm of the ratio of the current through the loud speaker to the minimum current is plotted as a function of the difference between the corresponding

reverberation times. Each point represents the mean of 50 observatoins of current and time, under conditions essentially as described under the Four Organ calibration, the loud speaker being substituted for the four organs. Observations for the tones C_3, C_4, C_5, and C_6, (256–2,048 vibs./sec.) were first made in October and November, 1927, and again in

FIG. 5.

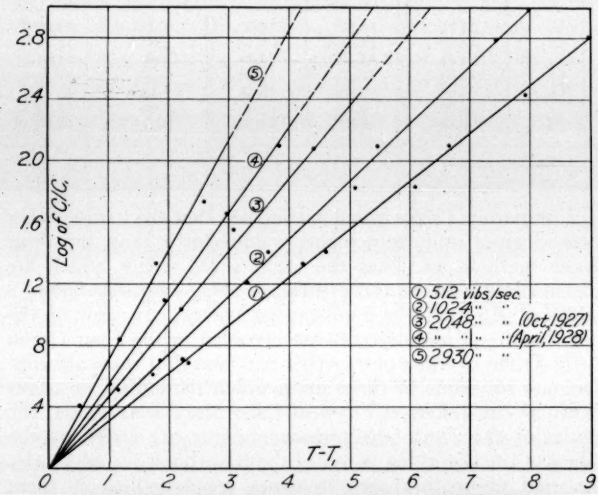


Increase of Reverberation Time vs. the logarithm of loud-speaker current ratio, at 128 and 256 vibs/sec.

April, 1928. With the single exception of C_6, the data in the two experiments were sufficiently congruent that all the points fell very close to a single straight line. In the case of C_6, although each set of points showed a linear relation between the logarithm of the current ratios and the difference in reverberation times, yet the slopes of the two lines for this particular frequency *do not* agree. The later experiment shows an apparent rate of dissipation of sound energy 17.5 per cent. greater than the earlier one, yet the reverberation time using the organ pipe showed only a slight difference and that in the

opposite sense. Since the acoustical conditions were essentially identical in the two experiments, the difference must be ascribed to a difference in the performance of the loud speaker and suggests that as a source of sound for work of this character its constancy can not be relied upon with entire confidence.

FIG. 6.



Increase of Reverberation Time vs. logarithm of current ratio.

We shall for the moment assume that the acoustical output of the loud speaker is proportional to the square of the current. Then

$$E = kC^2$$

$$a' = 2 \times 7.70 \left(\frac{\log C_n/C_1}{t_n - t_1} \right) \tag{9}$$

or a', the absorbing power of the room at any frequency with the loud speaker in is 15.4 times the slope of the corresponding line, (Figs. 5 and 6). In Table 2 are given the results of the loud speaker measurements. Here, as in Table 1, the T and

T' are the values of the reverberation times, using the organ pipes without, and with, the loud-speaker apparatus in the Sound Chamber.

TABLE 2.

Sound Chamber Calibration Loud Speaker Method.

Tone	T	T'	a'	a	Log E/i (Organ pipe)
C_2	14.70	14.58	4.07	4.03	10.26
C_3	14.58	14.24	5.18	5.07	12.22
C_4	14.25	13.43	4.81	4.56	11.01
C_5	12.80	11.70	5.75	5.32	11.35
[1]C_6	9.80	9.35	8.55	8.15	13.19
[2]C_6	9.60	9.24	7.28	7.02	11.54
$F\#_6$	7.18	6.57	10.90	9.94	12.30

[1] October, 1927.
[2] April, 1928.

Comparing Tables 1 and 2, it is seen that the loud-speaker method gives uniformly higher values for a than the Four Organ method, and that the latter gives values which are intermediate between those obtained using Professor Sabine's values of E/i, and the loud-speaker values. In view of the fact that fewer assumptions are involved in the Four Organ method than in either of the other two, and that these assumptions are the same as those upon which the earlier measurements at the Jefferson Physical Laboratory were made, the results of the Four Organ measurements are taken as the values of the absorbing power of the Riverbank Sound Chamber, and absorption measurements are based upon these values. At the tones 512 and 1,024, the agreement between the results of the Four Organ and the Loud-speaker methods is fairly close.

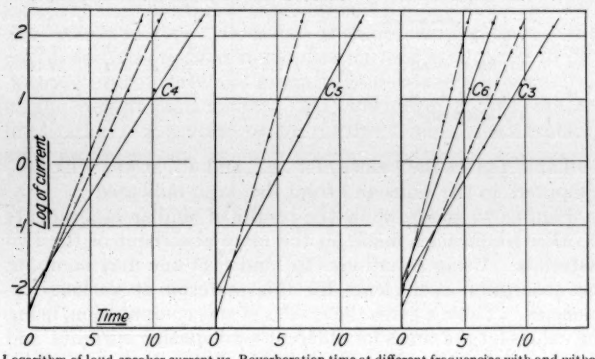
Absorption Measurements Using Loud-Speaker Source.

In Fig. 7*a* are shown the data for the reverberation times at 512 vibs./sec. at different current values in the loud speaker, (*a*) in the empty Sound Chamber, (*b*) with 48 square feet of each of two highly absorbent materials. These data afford two independent means of computing the absorption coefficient of each of the two materials.

(1) Assuming that under fixed room conditions the acoustic output of the loud speaker, and hence the average intensity

in the steady state, is proportional to the square of the loud speaker current, the values of a', a'', and a''', total absorbing power of the room in each of the three conditions may be computed by the equation.

FIG. 7a, 7b, 7c.



Logarithm of loud-speaker current vs. Reverberation time at different frequencies with and withou absorbing material in the room.

$$(10) \qquad a' = 2 \times 7.7 \log_{10} \frac{C_1'/C_2'}{t_1' - t_2'} = 2 \times 7.7m,$$

where m is the slope of the straight line representing the experimental points.

(2) Assuming equal acoustic outputs at equal currents under two room conditions, a'' may be computed from a', t', and t'', t' and t'' being the times at a given current value, before and after the introduction of the absorbent material, respectively

$$a't' = 7.70 \log\left(\frac{4E}{a'vi}\right),$$

$$a''t'' = 7.70 \log\left(\frac{4E}{a''vi}\right).$$

Eliminating E/vi, we have

$$(11) \qquad a'' = \frac{1}{t''}\left(a't' - 7.7 \log \frac{a''}{a'}\right).$$

Equation 11 may be solved by a series of approximations starting with the approximation $a't' = a''t''$ and putting successively the approximate values of a'' in the logarithmic correction term.

TABLE 3.

Computed by	a'.	a''.	a'''.
Equation (10)	4.83	6.56	7.80
" (11) log C = 2.2	"	6.21	7.26
" (11) " " = 1.0	"	6.05	7.12
" (11) " " = .0	"	5.91	6.82
" (11) Organ pipe	"	6.63	7.69

Table 3 gives the values of a', a'', and a''' at 512 vibs./sec. computed, in the ways and from the data, indicated:

Figures 7*b* and 7*c* show the results of similar experiments at other frequencies made on the more absorbent of the two materials. Using equations (10) and (11) one may compute the absorption coefficients for this material at various frequencies. Table 4 gives the results of this computation, using the values for the times for different loud-speaker currents, and also for the organ pipes under the same room conditions. The values of a' for the empty room are taken from the slopes of the straight lines shown.

TABLE 4.

Source.	Computed from	Coefficients.			
		C_{512}.	C_{1024}.	C_{2048}.	C_{4096}.
Loud Speaker	Equation 10	.44	.68	1.06	.85
Loud Speaker (log c = 2.2)	" 11	.28	.58	.79	.70
Loud Speaker (log c = 0)	" 11	.17	.44	.58	.56
Organ Pipes	" 11	.35	.65	.79	.75

The coefficients computed from these data and in the manners indicated do not agree, so that we see here an example of the discrepancies already referred to as existing between the values obtained by different observers. Moreover, the computed value of the absorption coefficient at any frequency is less for small than for large loud-speaker currents. Obviously there is something wrong either with our fundamental theory or with some of the assumptions made in applying it, using the loud speaker as a source of sound.

Inspecting Figs. 7*a*, 7*b*, and 7*c*, one notes that, if the straight line representation of the experimental points be extrapolated, the line for the deadened room cuts the axis of zero time at a lower value of the current than does the line for the bare room in every case. Now a zero reverberation time means that the initial average intensity is the minimum audible intensity. We thus arrive at the conclusion that, granting all the assumptions made, less current is required to produce a sound of threshold intensity in the deadened room than in the reverberant room. This conclusion contradicts the implication of Equation 10, for putting t' and t'' each equal to zero, we have

$$\log \frac{E'}{va'i} = \log \frac{E''}{va''i} = 0,$$

whence

$$\frac{E'}{a'} = \frac{E''}{a''}$$

or, for the threshold intensity the acoustic output of the source should be proportional to the total absorbing power of the room, which would call for larger current with greater absorbing power.

Two solutions of the difficulty suggest themselves. The first, is that the absorption coefficient of the material, considered as a function of the intensity of the sound is not a constant, but a quantity which increases with increasing intensity. The figures in Tables 3 and 4 would appear to justify this explanation. This would lead to the conclusion that the experimental points of Figs. 7*a*, 7*b*, and 7*c* should be represented not by straight lines but by curves slightly concave upward. Such an hypothesis while explaining the results of the present experiments, would also necessitate a modification of the whole Reverberation Theory, which, as we have seen, is based upon the assumption of an absorption coefficient independent of intensity. In the present state of our knowledge as to the mechanics of the absorptive process, the possibility of absorption being a function of intensity must be admitted. On this hypothesis, reverberation measurements based on the variation of the acoustical output of the source would always, as in the present instance, lead to

higher values of the absorption coefficient than those based on the application of Equation 11, with a source of fixed acoustic output. Likewise, coefficients obtained using a powerful source will be greater than when a weak source is employed.

The second point calling for examination is the assumption that equal loud-speaker currents represent equal sound outputs under altered room conditions.[4] Take the extreme case, and consider that the walls are perfectly reflecting and that no sound energy is dissipated in the room. One remembers at the same time that the standing wave system is being continually shifted by the motion of the large reflectors. In the steady state, under these conditions we must consider the loud speaker and the room as a single closed system from which no energy is radiated, and hence one in which no part of the electric power input would be used in generating sound. The acoustic impedance at the diaphragm is zero, and the power required to drive it is the same as though it were driven in vacuo. Now suppose an opening to be made in the Sound Chamber from which sound is radiated, or what is equivalent, that an absorbing surface be introduced. The sound energy of the system is no longer conserved, total impedance at the diaphragm is increased, and to maintain the same current, a higher driving voltage is needed than in the perfectly reflecting room. As a matter of fact, these considerations were not in mind when the experiments were performed. Voltage measurements were not made, the attenuator being adjusted only to give equal currents with and without the absorbent material present. Quantitatively, the importance of this effect depends upon relative magnitudes of the added acoustical impedance due to the presence of the absorbing material, and the sum of the motional impedance of the diaphragm and the electrical impedance of the driving circuit. In the type of loud speaker used in these experiments, the whole acoustical impedance is very probably less than 5 per cent. of the total impedance, so that while qualitatively the effect here considered may be adduced to explain the results, yet quantitatively it would seem quite insufficient.

Summed up, it is to be said that the present experiments

[4] See W. C. Sabine, "Collected Papers on Acoustics," page 278. Crandall, "Theory of Vibrating Systems and Sound," page 222.

with the loud speaker leaves us in a state of uncertainty either as to the unqualified validity of the Reverberation Theory or as to the propriety of the assumptions usually made in the use of the loud speaker as a sound source, while serving the very useful purpose of showing a possible source of discrepancy between the results obtained by different observers. The whole subject of the application of telephonic electrical measurements to problems of architectural acoustics calls for very careful fundamental research.

The inconclusive results of the investigation with the loud speaker up to this point are therefore presented in the nature of a "progress report" with the hope that the facts brought out may be useful to other workers in the field of acoustical measurements. The subject is being still farther studied in this laboratory. Meanwhile, adhering to the methods and assumptions made by W. C. Sabine, the Four Organ Calibration of the Sound Chamber, and organ pipe sources are retained as giving results that are congruent with those now used in practice.

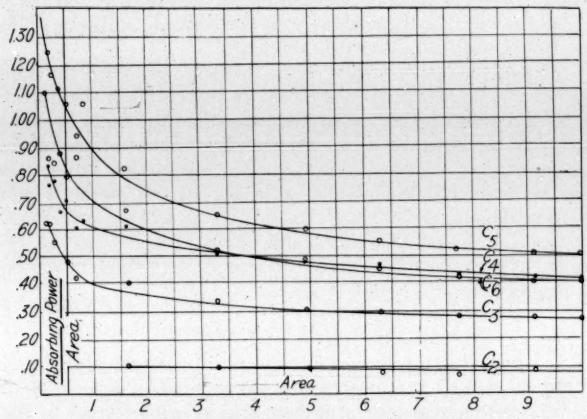
AREA EFFECTS IN ABSORPTION MEASUREMENTS.

In an investigation conducted in 1922, upon the absorption of impact sounds, it appeared that the increase of absorption of sounds of this character was not strictly proportional to the area of the absorbent surface, introduced into the Sound Chamber, and that small samples showed markedly greater absorption per unit area than large samples of the same material. The investigation was extended, using sustained tones, and the same phenomenon was observed as in the case of short impact sounds. In Fig. 8 are shown the apparent absorbing powers per unit area of a highly absorbent hair felt plotted against the area of the test sample. These values were computed by means of equation (11) from observations using organ pipes as sources of sound.

The same effect under somewhat less ideal conditions was observed in the case of the absorbing power of (transmission through) an opening. A large window in an empty room, $30 \times 30 \times 10$ ft. was fitted with a series of frames so that the area of the opening could be varied, the ratio of dimensions being kept constant. The absorption coefficient for these

openings at 512 vibs./sec. varied from 1.10 to .80 as the size was increased from 3.68 to 30.2 square feet. A doorway 8 × 9 ft. in a room 30 × 30 × 9 ft. showed an apparent coefficient as low as .65. (In this case, conditions were complicated by reflection of sound from the ground outside.)

FIG. 8.



Effect of area test sample upon measured value of the absorption coefficient.

In view of the fact that the earlier measurements of Professor Wallace Sabine were based on the open window as an ideal absorber with an assumed coefficient of 1.00, it was of interest to recompute from his data the values of the absorption coefficients of openings. These data were used by him, assuming a coefficient of 1.00 in the determination of the constant K of the simple reverberation formula. Fortunately the data necessary for these computations are found in his original notes, but unfortunately for the present purpose, only the total open window area is given and not the dimensions of the individual openings. The figures are shown in Table 5.

In table 5 w is the total area of the open w indows, and a and a' are computed from the equation

$$at = \frac{9.2V}{v}\left(\log_{10}\frac{4E}{avi}\right).$$

TABLE 5.

Room.	V.	t.	t'.	a.	w.	a'.	$\frac{a'-a}{w}$
Fogg Art Museum							
1 pipe	96	4.59	3.00	3.99	1.86	5.85	1.00
16 pipes (7.6×1 pipe)	"	5.26	3.43	3.86	1.86	5.80	1.04
J.P.L.							
Room 15	202	1.78	1.66	19.15	1.34	20.5	1.01
" "	202	1.78	1.56	19.15	2.67	21.7	.96
" "	202	1.78	1.41	19.15	5.28	23.7	.86
Room 1	1,630	3.88	3.26	65.0	12.2	76.2	.92
Room 41	1,960	3.41	2.88	87.0	14.9	101.2	.88

It will be noted that there is a marked variation in the values of the coefficients for the open window. The data for Room 15 show a decrease in the apparent absorbing power as the area of the individual openings is increased, quite in agreement with the results obtained in this laboratory.

One finds an explanation of these facts in the phenomenon of diffraction, and the screening effect of an absorbent area upon adjacent areas. In the Reverberation Theory, we assume a random distribution of the direction of propagation of sound energy. Thus on the average, two thirds of the energy is being propagated parallel to the surface of the absorbent material. Neglecting diffraction, in such a distribution, only that portion travelling at right angles to the absorbent surface would be absorbed by a very large area of a perfectly absorbent material. Due to diffraction, however, the portion travelling parallel to the surface is also absorbed over the entire area, but more strongly at the edges.

The following experiment illustrates this "edge effect." Strips of felt 12″ wide were laid on the Sound Chamber floor, forming a hollow rectangle 8 × 5 ft. (2.44 × 1.53 meters). The increase in the absorbing power due to the sample was measured. The space inside was then filled and the increase produced by the solid rectangle measured. The absorbing power per unit area of the peripheral and central portions are given below:

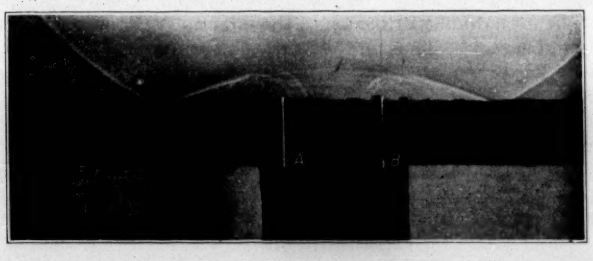
	C_2.	C_3.	C_4.	C_5.	C_6.
Peripheral area	.12	.42	.69	.88	.68
Central area	.05	.27	.24	.29	.30

The screening effect of the edges is obvious, and serves to explain the decrease in absorbing power per unit area shown in Fig. 8. In a similar manner, long narrow samples show more effective absorbing power than equal areas in square form, as shown below:

Area (sq. m.).	Dimensions.	Coefficient.			
		C_1.	C_4.	C_8.	C_{16}.
1	330 × 33 cms.	.62	.78	1.01	.73
1	100 × 100 "	.42	.62	.86	.70
2	666 × 30	.53	.76	.93	.71
2	141 × 141	.37	.55	.73	.59

The fact that small samples may show an apparent absorption coefficient greater than unity calls for notice. It is to be remembered that we are here dealing with linear dimensions

FIG. 9.



Sound pulse incident upon a barrier with an opening. A–B marks the edges of the opening.

that are of the order of or even less than the wave length of the sound. The mathematics of the problem involves the same considerations as that of radiation of sound from the open end of an organ pipe or the amplification by a spherical resonator. Diffraction plays an important role, and just as in the case of the resonator energy is drawn from the sound field around the resonator to be re-radiated, so the presence of the small absorbent sample or small opening affects a portion of the wave front greater than its own area. Qualitatively,

the effect is shown by the sound photograph of Fig. (9). which shows a sound pulse reflected from the surface of a barrier with an opening. The cross section of the portion cut out of the reflected pulse is clearly greater than the cross section of the opening.

Effect of Tone Quality.

The effect of tone quality upon the measured value of the absorption coefficient is shown in Table 6.

TABLE 6.

Coefficient at 512 vibs./sec.

Sample.	Open Diapason.	Stopped Flute.	Loud Speaker.
1	.36	.24	
2	.43	.31	.31
3	.18	.11	
4	.19	.13	
5	.63	.53	.54

Under the same room conditions, and with very nearly equal initial intensities of sound, as measured by the reverberation times in the empty room, the absorption coefficients of different materials were measured at 512 vibs./sec. using in turn an open diapason pipe, and a stopped flute pipe. For comparison, measurements were made on two of the samples using the loud speaker as a source. The open pipe gave of course the full series of harmonics, the overtones being marked, but not persisting in the reverberant sound longer than the fundamental. The odd harmonics were present in the stopped pipe, but much less prominent, so that the tone approximated a pure tone. Due to the electrical filters, the tone of the loud speaker was practically free from harmonics. The uniformly higher values of the absorption coefficients, shown by the measurement with the open diapason pipe, and the close agreement between stopped pipe and loud speaker values indicate that complex tones are more strongly absorbed than pure tones of the same pitch and intensity.

Cffiicoeents of Materials.

In the light of the foregoing, it is apparent that in giving the absorption coefficients of any material, one must specify carefully the test conditions that involve the various factors

that have been shown to affect the measured values of these coefficients. Further, in comparing the relative efficiencies of two materials as means of controlling reverberation, it is essential that the values of the absorption coefficients should have been determined under identical conditions. The following are the conditions of test that have been adopted at the Riverbank Laboratories and maintained in all measurements of absorption coefficients.

1. Volume of Sound Chamber—286 cubic meters.
2. Absorbing power of empty room determined by Four Organ Pipe Calibration.
3. Sound sources—open diapason organ pipes speaking at 4 inch pressure.
4. Test samples, 1.83 × 2.43 meters, 4.46 sq. meters (6×8 ft.).
5. The powers of the pipes and initial intensities of test tones are, approximately, as follows:

	Frequency.					
	128.	256.	512.	1,024.	2,048.	4,096.
Power, ergs/sec.	20,000	5,000	4,500	10,000	1,500	1,000
Initial intensity / Threshold Intensity	10^6	4×10^7	2.7×10^8	1.8×10^8	3.8×10^7	12×10^6

The precise value of the ratios of initial to threshold intensity of course are functions of the absorbing power of the room, of the power of the source and the acuity of hearing of the observer. They simply serve to give the order of magnitude of initial sound intensities, measured in threshold of audibility, of the test tones used.

Table 7 gives the values of the coefficients of various materials that have been measured under the above test conditions. Many of these tests have been made for the manufacturers of the respective materials, and grateful acknowledgment is made in each case for permission to include these figures in the present table. In the use of these figures, it should be remembered that slight variations in the physical properties may cause considerable variation in the absorption coefficients. In some cases it is impossible to specify these properties with exactness. Thus, for example, in felt ma-

terials slight variation in thickness will cause a considerable variation in the coefficient over the range from 256–1,024 vibs./sec. For this reason, as well as for the fact that extreme precision can not be claimed for absorption measurements even under the best conditions, a tolerance of about ±3 per cent. of the value given is allowable. For practical purposes of acoustical correction, this degree of precision is amply sufficient.

TABLE 7.

Material.	Pitch.					
	128.	256.	512.	1,024.	2,048.	4,096.
	Coefficient.					
1. Acoustic-Celotex, Type A perforated fiber board, $\frac{1}{2}$″ thick, 441 holes per sq. ft., $\frac{3}{16}$″ diameter $\frac{1}{2}$″ deep, plain side exposed		.20	.21	.19	.17	.24
2. Acousti-Celotex, Type B same as Type A, but with perforations exposed		.27	.40	.46	.42	.42
3. Acousti-Celotex, Type BB, $1\frac{1}{2}$″ thick, 441 holes per sq. ft. $\frac{3}{16}$″ diameter $1\frac{1}{2}$″ deep		.39	.63	.73	.55	.46
4. Acousti-Celotex, (tested 1924) 1″ thick, 400 holes per sq. ft. $\frac{3}{4}$″ deep		.32	.46	.66	.53	.47
5. Akoustolith Tile, $\frac{1}{8}$″ thick, fine texture cemented to clay tile	.06	.22	.28	.48	.50	.31
6. Balsam Wool, soft wood fiber, paper backing, scrim facing, 1″ thick .254 pounds/sq. ft.	.10	.27	.50	.68	.56	.48
7. Same covered with perforated metal cover, $\frac{1}{16}$″ holes, 64 per sq. in.	.09	.25	.48	.66	.57	.47
8. Standard Celotex $\frac{1}{16}$″ thick, on 1″ Furring		.16	.22	.20	.16	.15
9. The same on 2 × 4″ studs	.19	.14	.13	.14	.14	.16
10. Draperies, hung straight, in contact with wall, cotton fabric, 10 oz. per sq. yd.	.03	.04	.11	.17	.24	.35
11. The same, cotton fabric 14 oz. per sq. yd.	.04	.07	.13	.22	.32	.35
12. The same, velour, 18 oz./sq. yd.	.05	.12	.35	.45	.38	.36
13. The same as No. 12, hung 4″ from wall	.06	.27	.44	.50	.40	.35
14. The same as No. 12 hung 8″ from wall	.08	.29	.44	.50	.40	.35
15. Cotton fabric 14 oz./sq. yd. draped to $\frac{1}{2}$ its area	.03	.12	.15	.27	.37	.42
16. The same as No. 15, draped to $\frac{3}{4}$ area	.04	.23	.40	.57	.53	.40

TABLE 7.—*Continued.*

Material.	Pitch.					
	128.	256.	512.	1,024.	2,048.	4,096.
	Coefficient.					
17. Same as No. 15 draped to ½ area	.07	.31	.49	.81	.66	.54
18. Felt, Standard 1", all hair	.09	.34	.55	.66	.52	.39
19. Felt, Asbestos-Akoustikos, (hair and asbestos fiber) ½" thick	.07	.14	.31	.51	.51	.43
20. The same ¾" thick	.08	.23	.45	.65	.56	.46
21. " " 1" thick	.11	.31	.59	.68	.58	.46
22. " " 1½" thick	.13	.41	.73	.73	.58	.46
23. " " 2" thick	.21	.46	.79	.75	.58	.46
24. " " 3" thick	.33	.56	.79	.77	.58	.46
25. Flax-linum, semi-stiff flax fiber board ½" thick	.09	.15	.34	.57	.51	.47
26. Masonite, Standard ½" board (Pressed wood fiber), laid on 1" furring 18" O.C.	.09	.30	.33	.32	.30	.37
27. The same nailed to 2 × 4" studs, 16" O.C.	.16	.26	.34	.36	.30	.25
28. The same, nailed to 1 × 2" furring 16" O.C.	.15	.26	.31	.32	.30	.28
29. 1" Nashkote AAX, 1" felt, with cotton fabric cemented on surface two coats special paint	.11	.25	.34	.46	.48	.36
30. Nashkote B-332, 1" felt with perforated oil-cloth, $\frac{3}{32}$" perforation, 10 per sq. in.	.11	.31	.67	.81	.64	.50
31. Plaster, gypsum on wood lath on wood studs, rough finish	.016	.032	.039	.050	.030	.028
32. The same, with smooth finish ("lime putty")	.020	.022	.032	.039	.039	.028
33. Plaster, lime on wood lath on wood studs, rough finish	.027	.046	.060	.085	.043	.056
34. The same, smooth finish	.024	.027	.030	.037	.019	.034
35. Plaster, "Calacoustic" ½" thick	.06	.10	.14	.15	.15	.20
36. Plaster, Sabinite ½" thick	.06	.16	.21	.29	.34	.37
37. Stockade slab, Wood fiber, cemented with magnesite, 1" thick	.11	.13	.27	.50	.63	.40
38. The same 2" thick	.09	.35	.60	.67	.45	.53

STATISTICAL DESCRIPTION OF THE SIZE PROPERTIES OF NON-UNIFORM PARTICULATE SUBSTANCES.[1]

BY

THEODORE HATCH and SARAH P. CHOATE.

INTRODUCTION.

IT is a well recognized fact that the size properties of a non-uniform particulate substance are influenced by the particle size of the material. It has not been possible to state this relationship as a rigid law, however, owing to the absence of a mathematical definition of particle size.

In the present paper an attempt is made to define particle size by means of well-known statistical methods and to indicate the mathematical laws of relationship between particle size, thus defined, and certain size properties of non-uniform particulate substances, namely, the number of particles per gram of material and the specific surface of the substance.

STATISTICAL ASPECTS OF THE PROBLEM.

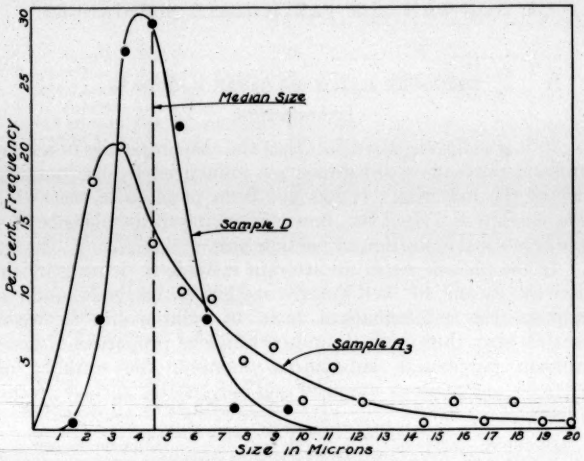
If one measures a large number of particles in a sample of solid particulate matter, the particles will be found to vary in size. If these measurements are arranged in groups of equal size intervals, each group will include a certain percentage of the entire number of measurements, and if the percentage frequency of each group is plotted against the mid-value of sizes included, a "size-frequency" distribution curve for the material will result. The shape of this curve varies according to the size complex of the material. In general, however, curves obtained in this manner may be said to resemble a cocked hat, since they have a definite modal value and approach zero toward the ends. The curves are commonly asymmetrical, or "skewed." (See Fig. 1.)

The particle size of a non-uniform particulate substance is influenced by the shape of its size-frequency curve. This fact

[1] From the Department of Ventilation and Illumination, Harvard School of Public Health, Boston, Mass., and the Department of Sanitary Engineering, Harvard Engineering School, Cambridge, Mass.

is clearly indicated by the curves in Fig. 1 and the micro-photographs in Fig. 2. The median size [1] is 4.5 μ in each

FIG. 1.



Size-frequency curves of samples A_3 and D.

case, yet sample A_3 appears to be larger than sample D on account of the greater number of large particles in the former. It will be observed also that the size-frequency curves differ markedly in shape.

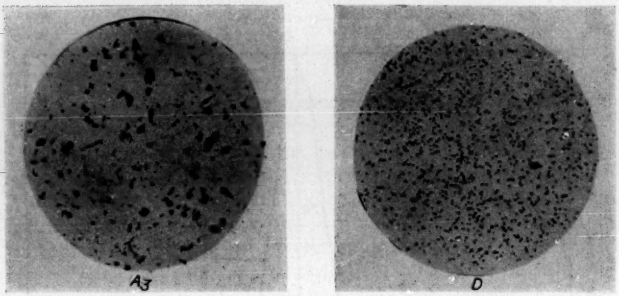
It is evident from the foregoing that particle size must be defined in terms of the shape of the size-frequency curves. Hence the shape characteristics, expressed in mathematical form, of the distribution curves of finely divided materials are needed.

It has been pointed out by Martin (1), Green (2), and others that the curves follow the law of probability, but, since they are generally asymmetrical or "skewed," it is evident that the normal probability equation, or ordinary "law of chance," does not apply, this law requiring, among other

[1] The median is that value than which 50 per cent. of the observations are smaller.

things, that the curve be symmetrical about a vertical axis. Recent investigations by Drinker (3) and by Loveland and Trivelli (4), however, have shown that the asymmetrical or "skewed" frequency curves of non-uniform particulate materials can, in general, be transformed into symmetrical curves

FIG. 2.



Microphotographs of samples A_3 and D at the same magnification.

following the ordinary "law of chance," or normal probability curve, when the logarithms of the sizes are substituted for the sizes themselves. Thus, the asymmetrical curves in Figure 1 give normal logarithmic curves, as in Fig. 3.

This fact is of great value in connection with the present problem, because it enables one to use the well-known parameters of the normal probability curve as "yard-sticks" for measuring the shape of the size-frequency distribution curves and hence the particle size of finely divided materials.

The mathematics of the probability curve is well-known and will not be discussed in this paper. The equation of the curve has the following form:

$$n = \frac{\Sigma n}{\sigma\sqrt{2\pi}} e^{-(X-M)^2/2\sigma^2},$$

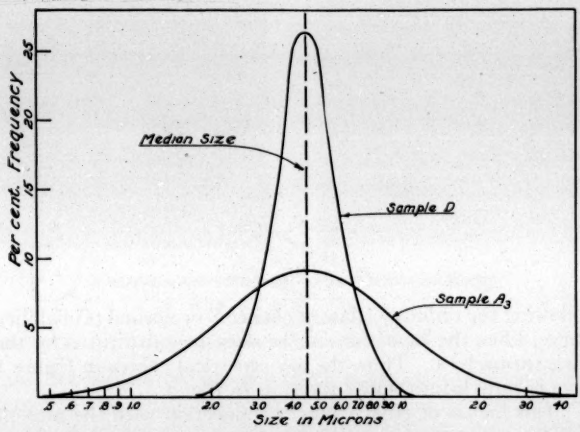
where n is the frequency of observations of value, X; Σn is the total number of observations; and M and σ are constants that determine the position and shape of the curve. The

constant, M, determines the position of the vertical axis of symmetry of the curve and is defined as follows:

$$M = \frac{\Sigma(nX)}{\Sigma n}.$$

It will be noted that it is also the arithmetic mean of the observations. The constant, σ, called the standard deviation,

FIG. 3.



Logarithmic size-frequency curves of samples A_3 and D.

is a measure of the dispersion of the observations from the mean. It is given by the following expression:

$$\sigma = \sqrt{\frac{\Sigma[n(X - M)^2]}{\Sigma n}}.$$

These two constants rigidly define the frequency distribution of a series of observations that vary according to the law of probability (5).

As stated above, a normal probability curve is given by the size-frequency distributions of non-uniform particulate substances when the logarithms of the sizes are substituted for the

measures themselves. Hence the parameters, M and σ, must be determined from the logarithms of the measures. Under this condition, they may be defined as follows:

$$\log M_g = \text{mean of logarithms} = \frac{\Sigma(n \log X)}{\Sigma n}$$

and

$$\log \sigma_g = \text{standard deviation of logarithms} = \sqrt{\frac{\Sigma[n(\log X - \log M_g)^2]}{\Sigma n}}$$

and are known as the log-geometric mean and log-standard geometric deviation, respectively.

The labor involved in the calculation of these two parameters can be considerably reduced by utilizing logarithmic probability paper (6), which allows a graphic solution of the problem. On this paper, the summation curve, or the curve obtained by integration of the equation of the logarithmic probability law, plots as a straight line. Thus, by plotting the percentage of particles below a certain size against that size, a straight line of best fit can be drawn through the plotted points.

The geometric mean is that value obtained by reading the 50 per cent. size.[2] It follows from the probability integral that

$$\sigma_g = \frac{84.13 \text{ per cent. size}}{50 \text{ per cent. size}} = \frac{50 \text{ per cent. size}}{15.87 \text{ per cent. size}}.$$

Thus, by determining the 84.13 per cent. and the 50 per cent. sizes from the fitted line, the geometric mean and the standard geometric deviation can be determined with considerable saving of labor.

INFLUENCE OF THE SHAPE OF THE SIZE-FREQUENCY CURVES UPON THE SIZE PROPERTIES OF NON-UNIFORM PARTICULATE MATTER.

It has been shown by Perrott and Kinney (7) and by Green (2) that the size properties of non-uniform particulate matter can be measured in terms of certain average diameters. It is assumed that the surface area of a single particle is a function

[2] The mean bisects the symmetrical frequency curve.

of the square of its diameter and the volume a function of the diameter cubed. Hence, for a non-uniform material, the diameter of the hypothetical particle having average surface area is given by

$$\Delta = \sqrt{\frac{\Sigma(nd^2)}{\Sigma n}},$$

when d is the diameter of each particle and n the number of particles having a diameter, d. In the same way, the diameter of the hypothetical particle having average volume is given by

$$D = \sqrt[3]{\frac{\Sigma(nd^3)}{\Sigma n}}.$$

It follows that the average surface area, $\bar{s}$, will be given by the product of Δ^2 and a constant depending upon the geometric shape of the particles. Hence we may write:

$$\bar{s} = \alpha\Delta^2,$$

where α is the area shape factor.[3]

Similarly, the average volume is given by

$$\bar{v} = \nu D^3$$

when ν is the volume shape factor.

But

$$\bar{v} = \frac{1}{\rho N}$$

when ρ is the density of the material and N the number of particles per gram. Hence

$$\nu D^3 = \frac{1}{\rho N}$$

The specific surface, S, of a substance is defined as the surface area per gram of material. Therefore we may write:

$$S = \bar{s}\, N = \frac{\alpha\Delta^2}{\nu\rho D^3}.$$

[3] The authors have used the symbol α to denote area shape factor in preference to σ, as suggested by Green (2), in order to avoid confusion with the standard deviation, which is usually denoted by σ.

In the present problem we are interested in the relation between the statistical parameters M_g and σ_g of the size frequency curves and the area and volumetric properties of non-uniform particulate materials.

Since

$$n = \frac{\Sigma n}{\log \sigma_g \sqrt{2\pi}} e^{-(\log d - \log M_g)^2/2 \log^2 \sigma_g}$$

it follows that

$$\frac{\Sigma(nd^2)}{\Sigma n} = \frac{\dfrac{\Sigma n}{\log \sigma_g \sqrt{2\pi}} \displaystyle\int_0^\infty d^2 \cdot e^{-(\log d - \log M_g)^2/2 \log^2 \sigma_g} \cdot d \log d}{\Sigma n}$$

and

$$\frac{\Sigma(nd^3)}{\Sigma n} = \frac{\dfrac{\Sigma n}{\log \sigma_g \sqrt{2\pi}} \displaystyle\int_0^\infty d^3 \cdot e^{-(\log d - \log M_g)^2/2 \log^2 \sigma_g} \cdot d \log d}{\Sigma n}.$$

It can be shown that these expressions take the following form:[4]

$$\frac{\Sigma(nd^2)}{\Sigma n} = e^{2 \log M_g + 2.0 \log^2 \sigma_g},$$

$$\frac{\Sigma(nd^3)}{\Sigma n} = e^{3 \log M_g + 4.5 \log^2 \sigma_g}.$$

Reduced to logarithms to the base 10, these expressions become

$$\log \Delta^2 = \log M_g^2 + 4.6052 \log^2 \sigma_g,$$

$$\log D^3 = \log M_g^3 + 10.3617 \log^2 \sigma_g.$$

Thus we may write

$$\log N = \log \frac{1}{\rho \nu} - \log D^3,$$

or

$$\log N = \log \frac{1}{\rho \nu} - \log M_g^3 - 10.3617 \log^2 \sigma_g \qquad (I)$$

and

[4] The authors are indebted to Professor E. B. Wilson and Professor C. R. Doering of the Department of Vital Statistics, Harvard School of Public Health, for assistance in the mathematics of this study.

$$\log S = \log \frac{\alpha}{\rho v} + \log \Delta^2 - \log D^3,$$

or

$$\log S = \log \frac{\alpha}{\rho v} - \log M_g - 5.7565 \log^2 \sigma_g. \qquad \text{(II)}$$

It is seen, therefore, that the size properties—surface area and volume—of non-uniform particulate substances are functions of the statistical parameters M_g and σ_g; that is to say, functions of the shape of the size-frequency curves.

EXPERIMENTAL.

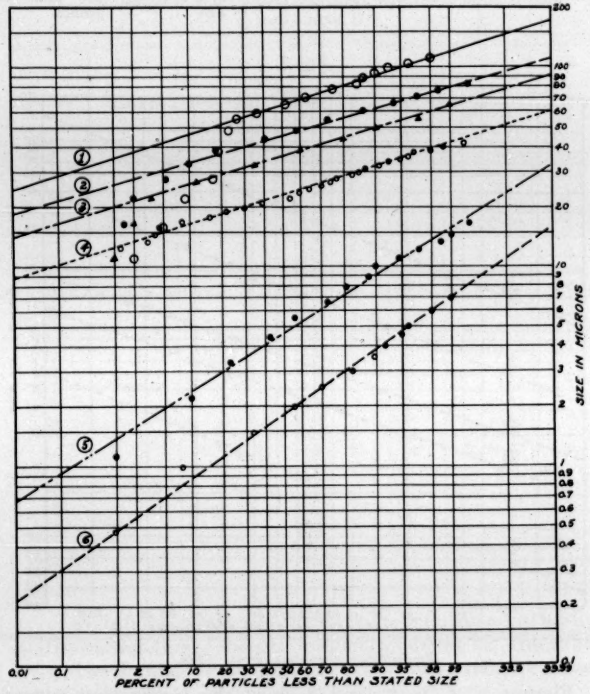
The following study was carried out in an effort to determine experimentally the law of variation between the parameters of the logarithmic probability curves and the volumetric and surface area properties of certain finely divided materials. For this work, three materials were selected: quartz (99.7 per cent. SiO_2), ground crystals of calcite (Iceland Spar) and granite dust obtained from the bag filters of a stone cutting shed.

These materials were screened through a 325-mesh sieve and the residue retained on the sieve was discarded. The dusts were then divided into fractions by elutriation with distilled water in a standard 1,000 c.c. graduate, according to the following time intervals: 0 to 2 minutes, 2 to 5 minutes, 5 to 10 minutes, 10 to 30 minutes, 30 minutes to 24 hours, 24 hours to 4 days. Each fraction was washed until the supernatant liquid showed no particles in suspension at the end of the time interval. Some of the silica dust was also fractionated in a centrifuge for varying lengths of time. The effect of this treatment was to give greater ranges of dispersion than was possible by ordinary elutriation methods. Twenty-six fractions were obtained.

Microscopic slides of the fractions were prepared according to Green's turpentine method (8) and particles measured by means of a filar micrometer. The horizontal diameter only was measured. In some cases this diameter was the major axis of the particle and in others it represented the minor axis, or some measure between the two. It was felt that the diameters measured uniformly in one direction would give a

representative picture of the size-distribution of an entire sample (9). In most cases, 200 particles were measured on each slide. The ordinates of the summation curves of the

FIG. 4.



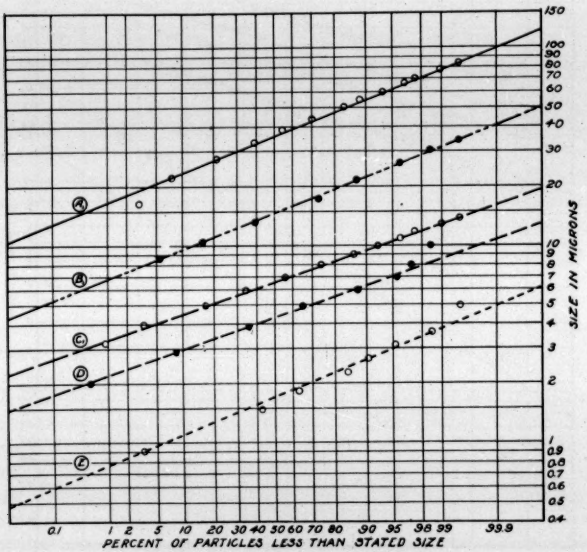
Size-frequency summation curves. Silica.

size-frequency distributions were then calculated according to the following schedule and the values from columns 2 and 5 were plotted on logarithmic probability paper. A standard class-interval of one filar unit was used.

Schedule for Computing Ordinates of Summation Curve.

1	2	3	4	5
Upper limit of group in filar units.	Upper limit of group in microns.	Frequency of group.	Total frequency < upper limit of group size.	Per cent. frequency < upper limit of group.

FIG. 5.



Size-frequency summation curves. Silica.

Figures 4, 5, 6, 7, and 8 show the summation curves obtained. In each case a straight line of best fit was drawn in by eye.[5] The geometric mean values were determined by reading the 50 per cent. sizes from the curves and the standard geometric deviations were computed from the 84.13 and 50

[5] This method of curve fitting is open to question; but, in most cases, an excellent fit was obtained.

per cent. sizes, as described above. Table 1, columns 4 and 5, give these data for the various systems studied.

TABLE 1.

Parameters of Log-Probability Curves, Number of Particles per Gram, and Tyndallmeter Readings of Non-Uniform Particulate Systems of Silica, Granite, and Calcite.

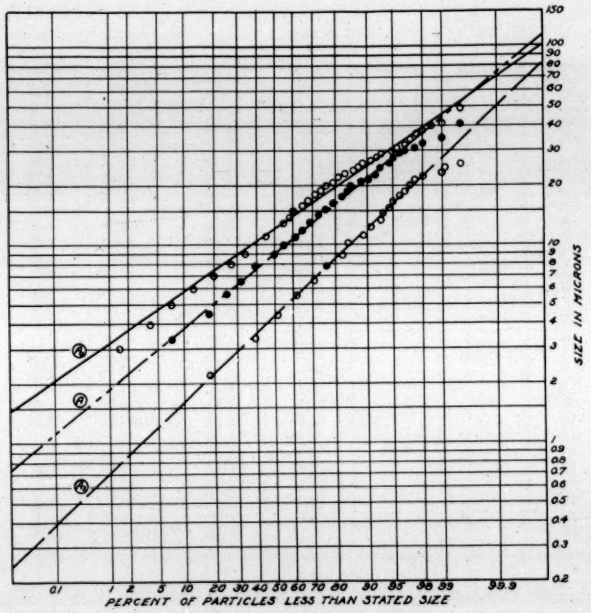
1. Sample Number	2. Material	3. Density ρ	4. Geometric Mean M_g	5. Standard Geometric Deviation σ_g	6. Number of Particles Per Gram in Millions N	7. Tyndall Reading at 50 Mg./Liter T_{50}
1	Silica	2.65	64.2	1.29	8.49	1.7
2	"	"	45.0	1.27	24.13	1.7
3	"	"	36.0	1.28	56.37	1.8
4	"	"	23.0	1.30	173.60	3.55
5	"	"	4.6	1.63	7,357.60	9.70
6	"	"	1.85	1.77		16.5
A	"	"	9.2	2.00	317.96	2.2
A_1	"	"	36.0	1.38	50.40	1.8
A_2	"	"	12.0	1.80	263.32	2.8
A_3	"	"	4.5	2.17	216.00	2.0
B_1	"	"	14.5	1.40	569.84	3.6
C_1	"	"	6.6	1.33	5,397.90	9.0
D	"	"	4.4	1.34	25,288.00	15.5
E	"	"	1.73	1.42		
7	Granite	"	72.0	1.35	8.80	1.10
8	"	"	46.0	1.46	18.05	1.35
9	"	"	28.3	1.42	55.79	2.9
10	"	"	16.5	1.55	210.00	3.75
11	"	"	4.5	1.73	6,480.00	6.5
12	"	"	1.45	1.69		
13	Calcite	2.75	69.0	1.26	9.39	1.8
14	"	"	47.0	1.32	19.91	1.9
15	"	"	37.5	1.30	38.92	2.0
16	"	"	19.3	1.39	163.70	4.0
17	"	"	6.1	1.60	9,332.00	11.3
18	"	"	1.15	1.35	647,000.00	25.0

Two other size measurements were determined in addition to the parameters of the size-frequency curves, viz. the value of N, or the number of particles per gram, and a relative measure of surface area.

The procedure for determining N was as follows: A portion of the dust was accurately weighed and placed in a flask together with a known volume of a suitable dispersing medium. The flask was then agitated until the dust particles were evenly dispersed throughout the liquid. This was easily accomplished in the case of large particles, but the

smaller sizes often flocculated badly and even prolonged agitation failed to disperse them completely. As the size of the dust increased, it became necessary to use dispersing media of higher viscosities, in order to keep the particles in suspension

FIG. 6.

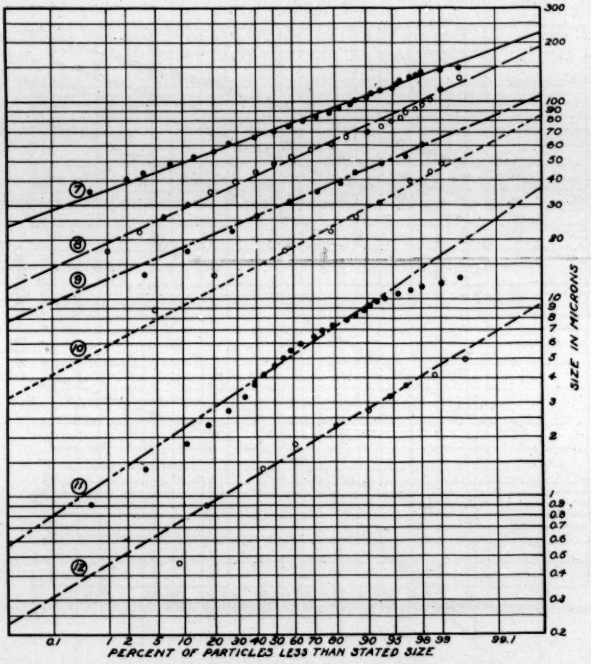


Size-frequency summation curves. Silica.

until a representative portion could be poured into the counting cell. Gelatin was found to be the most satisfactory dispersing medium. By mixing it with various percentages of water, liquids of varying viscosities were obtained, the desired viscosity for dispersion of a particular material being determined experimentally.

Counting cells of differing thickness were required for use under different magnifications. Thus with the low power it was possible to use the standard Sedgwick-Rafter cell which has a depth of 1.0 mm.; for the high power, a cell of 0.5 mm.

FIG. 7.



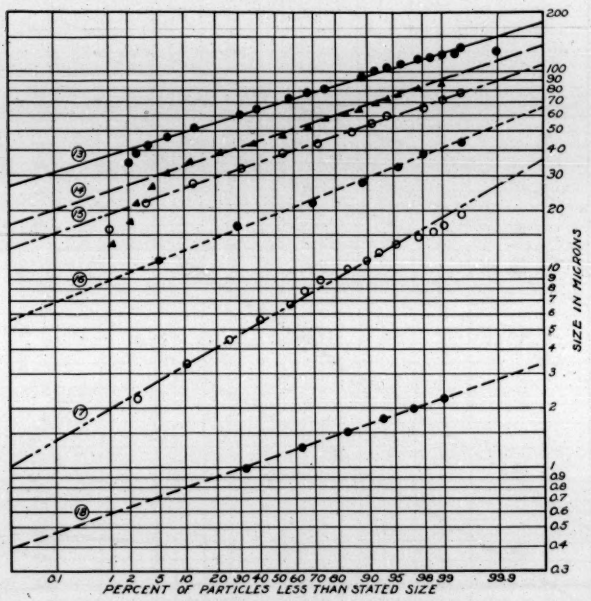
Size-frequency summation curves. Granite.

depth was required; and with the oil immersion objective, the blood cell (0.1 mm. deep) was used. Two cells of each material were prepared and ten fields counted in each cell. In all cases, the materials were prepared in dilution to give about 50 particles in a field.

Values of N for the materials under consideration are given in column 6 of Table 1.

The specific surface of a non-uniform particulate substance cannot be determined by any simple means such as was used in the determination of N.[6] It was necessary, therefore, to

FIG. 8.



Size-frequency summation curves. Calcite.

make use of one of the many indirect methods that have been developed. The Tyndallmeter (12, 13, 14) is of value here, because it is simple and rapid in its operation and gives fairly accurate results.

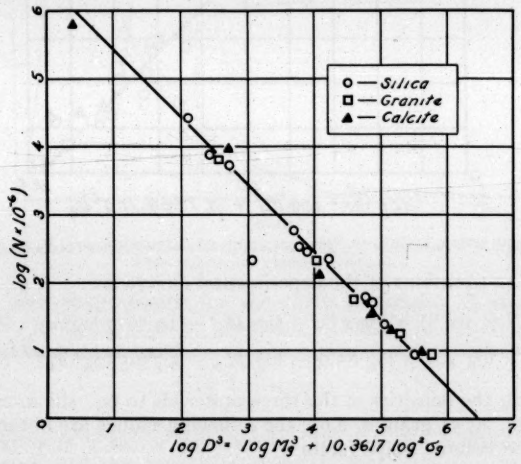
[6] Direct determinations of the surface area of quartz particles have been made by Martin (10) and more recently by Gross and Zimmerley (11), but the methods involved are complicated and could not be followed in the present investigation on account of lack of time.

The Tyndallmeter is an instrument which measures photometrically the strength of the Tyndall beam created by light passing through liquid or gaseous suspensions of particles. Within the particle size range found in the materials studied, the strength of the beam is proportional to the surface area of the suspended matter (15). Thus if suspensions of equal concentration of the same material are used, the Tyndall readings will give relative measures of the surface area in each case. Tyndallmeter readings for suspensions in distilled water at concentrations of 50 milligrams per liter were obtained for the twenty-six fractions and are tabulated in Table I, column 7.

DISCUSSION.

The data in Table I have been plotted in the manner suggested in equations I and II and are shown in Figs. 9 and

FIG. 9.

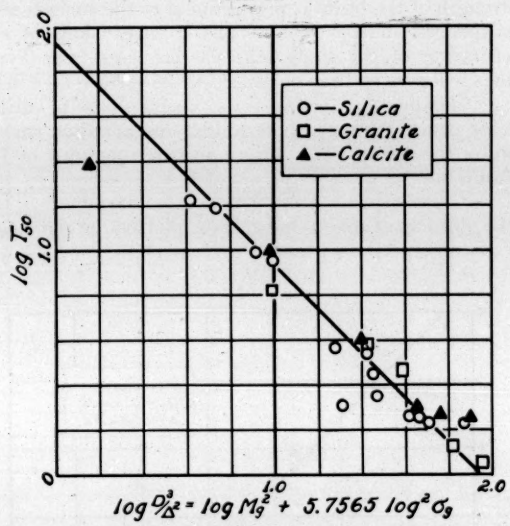


Relation between number of particles per gram and particle size expressed in terms of M_g and σ_g.

10. The plotted points follow the theoretical curves in a satisfactory manner and indicate that the theoretical assumptions made at the outset are in close agreement with the actual

relationship existing between size properties and the shape characteristics of the size-frequency distribution curves of non-uniform particulate substances.

FIG. 10.



Relation between Tyndallmeter reading and particle size expressed in terms of M_g and σ_g.

The equations of the experimental curves are:

$$\log (N \times 10^{-12}) = \log 2.69 - \log M_g^3 - 10.3617 \log^2 \sigma_g, \quad \text{(III)}$$

$$\log T_{50} = \log 85.0 - \log M_g - 5.7565 \log^2 \sigma_g. \quad \text{(IV)}$$

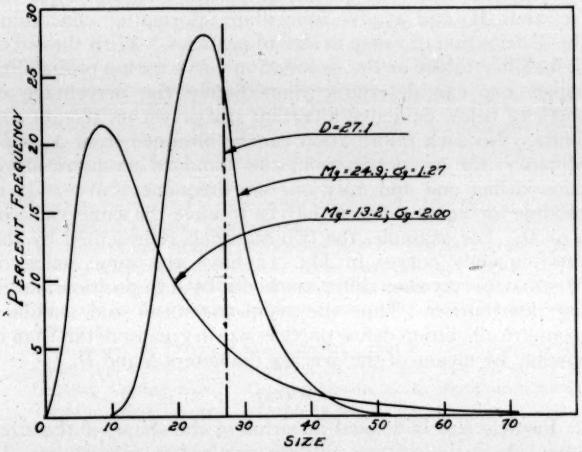
Taking the densities of the three materials to be: silica, 2.65; calcite, 2.75; granite, 2.65, the following values are obtained for the volume shape factor:

silica = 0.140,
calcite = 0.135,
granite = 0.140.

These values differ markedly from that of a sphere ($\pi/6 = 0.5286$) and indicate that the frequent assumption that particulate materials are spherical in shape may be in error by a considerable amount.

Since the Tyndall effect gives merely a relative measure of surface area, it is not possible to determine the true value of

FIG. 11.



Non-uniform size-distribution curves having the same value of D but differing in their geometric means and standard geometric deviations.

the area shape factor for the three materials. A relative value, however, may be obtained. Turning to equations II and IV, we may write

$$\kappa\left(\frac{\alpha}{\rho\nu}\right) = 85.0,$$

where κ is a factor representing the relation between the relative and the true area shape factors. Since $\rho\nu$ has a constant value, 2.69, the relative area shape factor is the same for all three materials, namely

$$\kappa\alpha = 228.65.$$

Definition of particle size in terms of M_g and σ_g possesses certain advantages over the use of the average diameters Δ and D. It has been shown that Δ and D are functions of M_g and σ_g. When calculated in the forms $\frac{\Sigma(nd^2)}{\Sigma n}$ and $\frac{\Sigma(nd^3)}{\Sigma n}$, considerable labor is involved. On the other hand, it has been shown that M_g and σ_g can be obtained graphically with considerable ease. Of greater importance, however, is the fact that M_g and σ_g give immediate information concerning the distribution or range in size of particles. With the aid of probability tables or the summation curve on log-probability paper, one can determine immediately the percentage of particles below or above a certain size or within certain size limits. No such information can be obtained from Δ or D. Moreover the geometric mean and standard geometric deviation define one and only one size-frequency curve. It is possible for many different curves to have the same value of Δ or D. For example, the two materials represented by the size-frequency curves in Fig. 11 have the same value of D^3: 20,000; yet they differ markedly both in position and in size distribution. Thus the geometric mean and standard geometric deviation define particle size in greater detail than is possible by means of the average diameters Δ and D.

SUMMARY.

Particle size is defined in terms of the shape of the size-frequency curves of non-uniform particulate substances. It is shown theoretically and experimentally that the size properties are closely correlated with the statistical parameters M_g and σ_g of the log-probability curves followed by the size-frequency distributions of such materials. It is further noted that this manner of defining particle size possesses certain advantages over the use of the average diameters Δ and D. These advantages are as follows:

1. The statistical parameters M_g and σ_g define one and only one size-frequency distribution curve.

2. Information concerning size-distribution and relative frequency of certain sizes can be obtained from M_g and σ_g.

3. The average diameters Δ and D are functions of M_g and σ_g. Thus M_g and σ_g give all information concerning particle size that can be obtained from Δ and D.

4. M_g and σ_g are determined graphically from the summation curves on log-probability paper, thus effecting considerable saving in labor over the calculation of $\frac{\Sigma(nd^2)}{\Sigma n}$ and $\frac{\Sigma(nd^3)}{\Sigma n}$.

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The Separation of Krypton and Xenon from the Air. A. LEPAPE. (*Comptes Rendus*, July 23, 1928.) The constant ratio between xenon and argon and between krypton and argon in air and in subterranean gases shows that there is no hope of finding in nature any mixture richer in xenon and krypton than the air itself which contains about 1 cc. of krypton and .09 cc. of xenon per cubic meter. Because both of these gases are soluble in liquid oxygen and have such low vapor tensions that they do not escape by evaporation they accumulate in the liquid oxygen left from the fractional distillation of the air. It is from this source that the rather few investigators who have prepared these rare gases have derived them. A table gives data for Ramsay, 1903, Moore, 1908, Antropoff, 1919 and for Dewar and Aston, 1923. Though Ramsay obtained only 7.5 cc. of krypton he got 5% of all that was present in his source. Dewar and Aston succeeded in getting 130 cc. of the gas with an efficiency percentage of .03. For xenon also Ramsay has the highest percentage, 6, while Dewar and Aston collected 575 cc. with efficiency of 1.8%. Lepape studied the recovery of the gases from liquid oxygen in a Claude apparatus for liquefying air. He found that at the beginning of the evaporation of the liquid oxygen the resulting gas contains about one part in a million of krypton while at the end one-thousandth consists of the two gases desired.

To separate the two gases from gaseous oxygen he caused the vapor coming from the liquid to traverse a tube holding 72 grams of cocoanut charcoal. The tube was in a Dewar bulb containing the evaporating liquid. Hence the charcoal was at the temperature of liquid oxygen. The charcoal adsorbs the krypton and xenon. Later these gases are driven off by heat and are freed of impurities by chemical means. The resulting mixture of the two gases is fractionated by the use of cocoanut charcoal at appropriate temperatures. With this method on the average 86% of the krypton present was recovered and 96% of the xenon. Several liters of krypton and one liter of xenon have been prepared and are being examined for industrial applications. Silica gel acts as well as charcoal in removing the two gases. G. F. S.

NOTE ON THE VISCOSITY OF GASES.

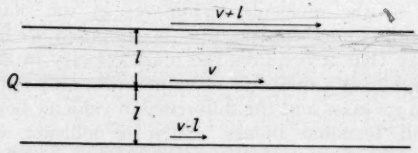
BY

S. S. KISTLER.

A careful examination of the customary derivations of the equation for the viscosity of gases reveals a rather surprising error in the chain of reasoning. Viscosity is generally conceived to be due to the transfer of momentum through the gas, and it is in the method of arrival at the value for the quantity of momentum transferred that the error occurs. It has apparently remained hidden because the equation obtained is doubtless correct.

In most methods of derivation the gas is assumed to be confined between two parallel planes of indefinite extent, whose distance apart remains constant, that are moving at a constant rate with respect to each other. The mass-velocity of the molecules in any plane parallel to the given plane is assumed constant. According to the kinetic theory, the number of molecules crossing unit area of a plane in a gas from one side in one second is $\frac{1}{6}Nc$ where N is the number of molecules per unit volume and c is the velocity of the molecule with average kinetic energy. The simpler derivations assume that the velocity gradient is unity.

FIG. 1.



Consider the plane Q, Fig. 1, parallel to the confining planes of the gas. From the principle of equipartition of energy it is permissible to assume that one third of the molecules are moving in a direction perpendicular to the plane with the velocity c. On the average, the molecules whose

paths terminate in the plane will come from a distance above and below it equal to the mean free path, l. There will be coming down to the plane from above $\frac{1}{6}Nc$ molecules per second and likewise the same number will be coming up from below. If the velocity gradient is unity, the molecules coming from the plane l distance below Q will come with l less velocity than the mass-velocity of Q and will therefore impart to it $\frac{1}{6}Ncm(v - l)$ momentum, while the molecules coming from the plane l distance above will possess on the average l greater velocity than the plane and will therefore impart to Q $\frac{1}{6}Ncm(v + l)$ momentum. The universal conclusion follows that consequently the momentum transfered across the plane is

$$\eta = \tfrac{1}{6}Ncm[(v + l) - (v - l)]$$
$$= \tfrac{1}{3}Nmcl,$$

where m is the mass of a single molecule and v is the mass-velocity of Q.

The above derivation has been copied many times with apparently little critical review. The mechanism of the transfer of momentum looks simple but upon examination it is seen that an assumption is tacitly introduced that is quite contrary to the fundamental assumptions of the kinetic theory. The molecule proceeding from a distance toward the plane is assumed to possess the mean mass-velocity of the plane from which it originated, and this assumption is probably correct, at least as a first approximation, but when the path of the molecule terminates in the plane under consideration something peculiar is supposed to happen in such a way that it acquires the mass-velocity of that plane and delivers to it a quantity of momentum only equal to the product of its mass and the difference in velocity between the initial and terminal planes. Such a collision would be inelastic, and since one of the fundamental assumptions of the kinetic theory is that the molecules are perfectly elastic it is difficult to see how this error has passed notice so long. Evidently the fact that the average horizontal velocity of the molecules leaving a plane is very nearly equal to the mass-velocity of the plane has led men to assume that each indi-

vidual molecule suffering a collision in a plane can be treated as though it left the plane with the mass-velocity superimposed upon its linear velocity.

I wish to call attention at this point to the method of adding momenta used in the customary derivations. As many molecules are moving from the plane Q to the upper plane as are coming down, so that the result is a transfer of $\frac{1}{6}Nmcl$ momentum to Q per second. The same thing is occurring between Q and the plane below and the result is the transference of $\frac{1}{6}Nmcl$ momentum per second from Q to the lower plane, usually expressed as a transfer of $-\frac{1}{6}Nmcl$ momentum from the lower plane to Q. By some turn of the imagination these two momenta add up to a transfer of $\frac{2}{6}Nmcl$ across the plane. As a matter of fact the molecules from above merely pass on their momentum to those below, and if the above mechanism for the transfer of momentum could be accepted the value for the viscosity of a gas would be half what it is found to be. The accepted derivation halves the momentum transferred by assuming inelastic impact in the plane, but compensates for this error by counting twice the momentum transferred. The final equation obtained, that is

$$\eta = \tfrac{1}{3}Nmcl$$

is unquestionably correct.

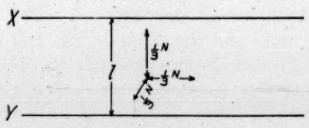
The above fallacy in counting momentum is of the same order as placing a coulometer on both sides of an electrolytic cell and adding the two values obtained in order to get the total current passed through the cell.

As O. E. Meyer pointed out,[1] there is a very close similarity between viscosity and pressure in gases. Let us turn for a moment to a consideration of pressure and its bearing on viscosity. Fig. 2 represents two imaginary parallel planes with the same mass-velocity situated in a gas. For our purpose the planes may be assumed to be stationary. As already stated, the pressure upon these planes may be assumed without loss of rigor to be equal to the pressure that one third of the molecules between the planes would produce

[1] Kinetic Theory of Gases, 1889.

if they were moving normal to the planes with velocities equal to that of the molecule with mean kinetic energy. In one second the number of such molecules producing impacts with one square centimeter of either of the planes is $\frac{1}{6}Nc$ and the force exerted upon that area by each impact is $2mc$,

FIG. 2.



because elastic impacts are assumed. The total force per unit area, pressure, will then be

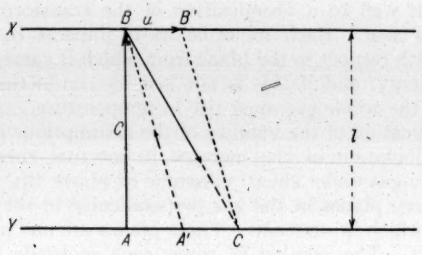
$$p = \tfrac{1}{3}Nmc^2.$$

Let us assume for simplicity that the distance between the planes X and Y is one mean free path and that all of the molecules traverse the intervening space without collision. Of course in the actual case the collisions will be distributed throughout the space and the chance that any one molecule will continue to move back and forth in a direction normal to the planes for even a fraction of a second is insignificant, nevertheless the validity of our assumptions is not vitiated by assuming that one third of the molecules are moving normal to the planes and experiencing impacts only in the planes. Although each plane is merely an imaginary locus of impacts between the molecules under consideration and those coming from beyond, for our purpose it may be imagined as a rigid elastic continuous surface, infinitely rough, so that regardless of the angle at which a molecule impinges, it is returned along the same path from which it approached.

Let us imagine now that the plane X is moving with a velocity u with respect to Y. Represent by the vectors c and u, Fig. 3, the velocities and directions of motion of a molecule leaving plane Y at A, and the plane X respectively. Assume u to be very small compared to c. The path of the molecule will be from A to B but its motion relative to the plane X will be along the path $A'B$. The distance AA' will be equal

to BB' and is so small compared to AB that the difference between the paths AB and $A'B$ is entirely negligible at low rates of shear. Since a molecule impinging on plane X will rebound along the same path, relative to the plane from which it approached, it will follow BC so that when the point of impact B has moved to B' the molecule will have moved to C, which has the same relative position with respect to the

FIG. 3.



plane as A' had when the molecule was at B. The actual path of the molecule will be ABC. We must not carry our artificial assumptions too far, however, as it is evident that the molecule impinging at C no longer is moving normal to Y nor has it the average velocity assumed for all molecules making impact. After the impact at B, this individual molecule loses itself in the chaotic motion of the aggregate and divides its added energy among many. The temperature of the mass is prevented from rising by conduction to the walls of the containing vessel.

It is plain to see that the pressure exerted upon X when it is in motion with respect to Y will not be directed normal to it but will be exerted along the direction $A'A$ so that there will be a component of force tangent to the plane whose magnitude per square centimeter will be u/c times the pressure, or

$$F = \frac{u}{c} \cdot \frac{1}{3} Nmc^2 = \frac{1}{3} Nmcu.$$

If now the rate of shear be taken as unity, $u = l$, and we have

$$\eta = \tfrac{1}{3}Nmcl,$$

which is the accepted equation for viscosity.

Of course it is immaterial which plane we take as moving with respect to the other so that we could just as well have considered the molecules moving down from the upper plane producing a tangential force on the lower plane equal to that we just calculated but opposite in direction.

The picture just drawn of the origin of viscosity in a gas lends itself well to a visualization of the transformation of work into heat. Each molecule as it impacts in a plane moving with respect to the plane from which it came, is given kinetic energy, and if this is not lost by conduction to the container the whole gas must rise in temperature.

An indication of the validity of the assumptions made lies in the calculation of the increase in internal energy of a monatomic gas under shear. Assume as above the existence of imaginary planes in the gas perpendicular to the velocity gradient, which is constant. These planes are one mean free path apart. The number of times each molecule strikes a particular plane will be $\frac{1}{6}\cdot c/l$. From Fig. 3 it is seen that the velocity of a molecule after impact with a moving plane is $\sqrt{c^2 + 4u^2}$ and consequently its kinetic energy is $\frac{1}{2}m(c^2 + 4u^2)$. Its increase in energy is therefore $2mu^2$. It follows that the increase in energy of each molecule in a second is

$$2mu^2 \cdot \frac{1}{6} \cdot \frac{c}{l} = \frac{1}{3} \cdot \frac{mcu^2}{l}.$$

The energy added to each cubic centimeter of gas under shear is force per square centimeter times distance per second. The distance one plane will move in a second with respect to a plane one centimeter distance will be u/l so that

$$\text{energy/cm.}^3\text{/sec.} = F \cdot \frac{u}{l} = \frac{1}{3} Nmcu \cdot \frac{u}{l} = \frac{1}{3} \cdot \frac{Nmcu^2}{l}.$$

Dividing by the number of molecules per cubic centimeter we get

$$\text{Energy per molecule} = \frac{1}{3} \cdot \frac{mcu^2}{l},$$

which checks the above calculation.

No such simple calculation of the increase in energy of translation of the molecules in a gas during shear can be made using the customary mechanism depicting viscosity, and unless one introduces assumptions not at all obvious about the way the molecule entering a new plane acquires the velocity of that plane, the calculation leads one far astray.

COLLEGE OF THE PACIFIC,
DEPARTMENT OF CHEMISTRY,
December 15, 1928.

Available Energy. ROBERT A. MILLIKAN. (*Science*, Sept. 28, 1928.) This address was delivered before the Society of Chemical Industry when the author received the Messel Medal for his work in relation to atoms.

Dr. Millikan directed attention to four recent achievements in pure science that are likely to have industrial importance—"1. the discovery of the relation between mass and energy; 2. the development of methods of making very exact atomic-weight determinations; 3. the discovery of the cosmic rays; 4. the development of relativity-quantum mechanics." The first of these, the quantitative equivalence of mass and energy was stated by Einstein. The energy in ergs that is equivalent to a mass stated in grams is found found by multiplying the number of grams by the square of the velocity of light. By combining No. 1 with No. 2, the determination of accurate atomic weights by Aston, the conclusion is reached that "the process of radioactive disintegration with the ejection of an alpha particle is a process that can take place only in the case of a very few of the very heavy and rare elements." This destroys the dream of replacing coal by the atomic energy of common elements, since "for the great majority of the elements, such as constitute the bulk of our world, are in their state of maximum stability already."

With regard to the cosmic rays they "are in fact the birth-cries of the infant atoms of helium, oxygen and silicon. We think that the atom building processes that give rise to the observed cosmic rays can take place only under the extreme conditions of temperature and pressure existing in interstellar, or intergalactic, space." Modern conceptions of matter lead "to the picture of a continuous atom-destroying process taking place under the extreme conditions existing in the interior of stars, and an atom-creating process continually taking place under the equally extreme conditions of just the opposite sort existing in interstellar space.

A limited amount of available energy can be obtained by the disintegration of atoms. An almost unlimited quantity of energy would be set free by the building up of atoms of common elements from the hydrogen contained in the waters of the earth but at the present time the conditions for such combination do not exist on the earth. The sun will continue to supply energy to the earth for a billion years to come. "When the matter of the sun has all been stoked into his furnaces and they are gone altogether out another sun will probably have been formed, so that on this earth or on some other earth—it matters not which some billions of years hence—the development of man may still be going on."

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PRESENT STATUS OF COMMERCIAL AIRPLANE ENGINE TESTING.

In March 1928, the Bureau of Standards began testing new commercial airplane engines as a basis for the granting of approved type certificates by the aeronautics branch of the Department of Commerce. The type certificate authorizes the use in licensed aircraft of any engine conforming to the specifications of the engine submitted for type test, and specifies the speed and power rating of such engines. To date, 21 type tests have been undertaken at the bureau and of this number 4 engines have been withdrawn, 11 have failed, and 6 have completed the test successfully. The results show that the average manufacturer should do more development work before going into production, and indicate the importance of type testing as a protection to the public.

The following engines have been approved and rated as a result of type tests at this bureau: Kinner (5-cylinder, radial, aircooled), 90 rated horsepower at 1810 revolutions per minute; Velie (5-cylinder, radial, aircooled), 55 at 1815; Comet (7-cylinder, radial, aircooled), 130 at 1825; Axelson (7-cylinder, radial, aircooled), 115 at 1800; LeBlond (7-cylinder, radial, aircooled), 90 at 1975; Harris (8-cylinder, vee, water-cooled), 90 at 1400. The Warner "Scarab" engine was approved and rated 110 horsepower at 1850 r.p.m. on the basis of a test at Detroit, observed by bureau engineers, before the present regulations went into effect. Thirteen other engines —including for example, the Curtiss "Challenger," the Wright "Whirlwind" and the Pratt & Whitney "Wasp"—have been approved on the basis of Army or Navy tests and have received commercial ratings recommended by the bureau.

The number of airplane engines intended primarily for commercial use which are under development at the present time exceeds all estimates made last year, and the bureau is planning to install additional testing facilities in the near

* Communicated by the Director.

future. A 9-cylinder radial aircooled engine made by the Aeromarine Plane & Motor Company is now under test. The following manufacturers are ready to submit engines for test: Hallett Aero Motors Corporation, Inglewood, Calif.; Velie Motors Corporation, Moline, Ill.; Rocky Mountain Steel Products, Inc., Los Angeles, Calif.; LeBlond Aircraft Engine Corporation, Cincinnati, Ohio; Brownback Motor Laboratories, Inc., New York City, N. Y.; Hurricane Motor Company, Inc., Houston, Texas; Menasco Motors Company, Los Angeles, Calif.; Alco Oil Tool Company, Compton, Calif.; MacClatchie Manufacturing Company, Compton, Calif.; and the Western Enterprise Engine Company, Los Angeles, Calif.

The airplane engine test requirements are stated on pages 40 to 42 of Aeronautics Bulletin No. 14. Applications for commercial airplane engine type tests may be addressed to the Bureau of Standards and should be accompanied by general information regarding the design of the engine. No fee is charged the manufacturer but he is required to furnish the gasoline and oil for use during the official test. His representatives are allowed to adjust the engine to their satisfaction before the test starts and to make any necessary adjustments between test periods.

RADIO EQUIPPED AIRPLANE.

THE Department of Commerce assigned to the bureau a cabin airplane for use in the development of radio aids to air navigation. This airplane was originally designed to carry four passengers and a pilot. In order to convert it to a flying laboratory two seats were removed and a permanent radio installation made. A set of complete transmitting and receiving equipment having a top which forms a desk was installed in front of the observers' seats. The essential navigation instruments are duplicated on an instrument board above this desk. On this instrument board and on the one in front of the pilot, visual reed indicators for the directive radio beacon and marker beacons are provided. Two persons may observe the operation of the radio equipment and at the same time be completely informed as to the operation of the air-

plane without disturbing the pilot. The top of the desk is shock mounted and available for use in testing experimental equipment which it may be desirable to try out in the air.

In order to insure satisfactory operation of the receiving and transmitting equipment the entire airplane structure was bonded and the engine ignition system completely shielded. The shielding is so successful that a very sensitive aircraft receiving set may be operated at full sensitivity without interference from the engine ignition. Power for the operation of the transmitting set is obtained from a generator driven by the airplane engine.

This airplane, which is in fact a flying radio laboratory, is being used in the study of the operation of the radio beacon system and other uses of radio under conditions of flight.

REPORT ON ORIFICE METERS FOR LARGE VOLUMES OF GAS.

THE March issue of the Bureau of Standards *Journal of Research* will contain a paper describing the orifice meter investigation carried out at Edgewood Arsenal in cooperation with the Chemical Warfare Service, and giving the principal results obtained with square-edged orifices such as are commonly employed in the commercial metering of large volumes of gas.

Absolute rates of discharge were measured by means of flow nozzles. This method has been investigated both experimentally and theoretically, and it appears to be the most convenient and accurate one now available for measuring high rates of flow. The discussion of this subject is an important part of the paper.

Of the 48 orifices tested, 26 were borrowed from several commercial firms and the remainder were made at the bureau. They were installed in 4, 6, and 8 inch pipes, with long straight runs in each direction, and with various combinations of pressure taps. They were tested with air at static pressures up to 275 lbs. per sq. inch and with differentials up to 70 per cent. of the upstream pressure.

The average results obtained are expressed in the usual manner by numerical tables of discharge coefficients applicable to the three most common locations of the pressure taps and

to various formulas for computing the rate of flow. Aside from these quantitative results, the following conclusions may be stated:

a. The discharge coefficient of a square-edged orifice for air, as defined in any of the usual ways, varies with the ratio of the differential to the static pressure, but it does not vary appreciably with the absolute value of the static pressure. The variations mentioned are negligible in most commercial practice, but at low static pressures, where the differential is sometimes a considerable fraction of the upstream pressure, they may be of considerable importance.

b. To produce duplicate orifice plates which shall all have the same discharge coefficient within one half of one per cent. requires very good mechanical work, even when the diameter of the orifice is one inch or more. With a few exceptions, the plates tested were all well made and in good condition; but the coefficients of individual plates often varied by as much as one half of one per cent. from the average of all, and sometimes by one per cent. without there being any obvious reason in the appearance of the plate.

c. With a given ratio of orifice to pipe diameter, the tests in the 6 and 8 inch pipes did not show any certain effect of absolute size. Similar plates in the 4 inch pipe gave, on the average, somewhat higher coefficients, but the experiments were not adequate to establishing any general relation between the coefficient and the absolute diameter.

In the autumn of 1924 the Bureau of Standards cooperated with a committee of the American Gas Association, under the Chairmanship of M. E. Benesh of the Peoples Gas Light and Coke Company of Chicago, in an investigation of several types of large gas meters. The experiments were carried out at one of the stations of the company just named and the absolute measurement of the rates of flow of air was effected by the use of a large gas holder. Among the metering devices tested were three very carefully made orifices installed in a 24 inch pipe and it is of interest to note that the discharge coefficients found for these orifices agree with the average results obtained or 6 and 8 inch pipes at Edgewood, well within the errors of measurement.

PRESENT STATUS OF COOPERATIVE ORIFICE METER TESTS.

EXTENSIVE tests of orifice meters are being conducted by the measurement committee of the natural gas department of the American Gas Association in cooperation with the Bureaus of Mines and Standards of the Department of Commerce.

The first group of tests was made at Cleveland, Ohio, in the fall of 1925, and consisted of a number of tests on three four-inch orifices in series with the first lift of a covered gas holder.

The second group of tests was made during the summer and fall of 1926 at Buffalo, N. Y., where some of the same equipment was utilized. The object was to determine the effects, upon orifice meter indications, of various kinds and combinations of pipe fittings placed close to an orifice meter flange. Based upon the results of these tests the committee prepared and issued a tentative code on the installation of orifice meters.

The tests made during 1927 may be divided into two groups. The first group was a supplement to the 1926 tests, and included a few check tests on the 1926 work and a short series of "disturbance fitting" tests using a 4 instead of an 8 inch pipe line. The second group of tests designated as "rate of flow tests," was made with orifices in an 8 inch line, ranging in orifice diameters from one to 6½ inches. The rates of gas flow through these orifices, as indicated by the pressure drop across the orifice, ranged from about 10 to over 400 inches of water. From these tests it was possible to determine a series of orifice coefficients for the range of sizes used.

The 1928 tests may be divided into three groups. The first group was a supplement to the 1927 rate of flow tests, being a short series of rate of flow tests with orifices in a 4 inch pipe. The second group of tests was designated as "high pressure" tests. The orifice under test was used in a line in which the pressure ranged from about 100 to about 300 lbs./in.^{2}. The third group of tests may be designated as "flange design" tests, and was made to determine what effect, if any, the interior form of an orifice flange has upon orifice measurements. In one case, the flanges were screwed on to the pipe until the ends of the pipe were flush with the faces of the flanges. In the other set, there was a considerable recess

within the flanges between the ends of the pipe and the flange faces. It was convenient to make many of the tests for the first and third groups together. A part of the second group or high pressure tests was made at Hastings, W. Va., where higher pressures were available than at Buffalo. The results of the 1928 tests are now being carefully studied.

During 1927 and 1928, H. S. Bean, Chief of the Gas Measuring Instruments Section of the Bureau of Standards, supervised the tests for the committee. Mr. Bean is now in southern California where he is carrying on the review of the 1928 data. He has discussed with Wm. Moeller, Jr., Chairman of the National Gas Bureau, F. A. Hough, Chairman of the Committee on Natural Gas Measurement of the Pacific Coast Gas Association, and other members of these organizations, the question of making some further high pressure tests. Hearty cooperation and support have been promised in the event such tests are made. Because of the favorable conditions found in southern California, plans for making further high pressure tests there are being considered. The desirability of making additional rate of flow tests on a large size line, possibly as large as 16 inches has also been discussed. In the event that the high pressure tests are made, it is probable that the cooperation of the Bureau of Mines will be sought. This bureau is also interested in methods for determining the so-called "open flow" of a gas well without resorting to the wasteful practice of "blowing" the well. Such tests could be made to advantage at the same time the high pressure tests are made, and have been considered in the discussion between Mr. Bean and the committee chairman named above.

STANDARD SAMPLES.

NEW standard samples that have been prepared recently are the standard sample of Fluorspar No. 79 which is priced at $2.50 per 60 grams and Ferrophosphorus No. 90 which is priced at $2.00 per 75 grams. The former contains 94.9 per cent. of calcium fluoride, 1.9 per cent. of silica, 1.0 per cent. of carbon dioxide, 0.14 per cent. of sulphur and small amounts of zinc, lead, copper, iron, aluminum, phosphorus, titanium, potassium, sodium, magnesium, barium, and manganese.

Sample No. 90 contains 26.17 per cent. of phosphorus. A sample of opal glass containing 68 per cent. of silica, 6 per cent. of fluorine, in addition to iron, aluminum, titanium, zirconium, calcium, magnesium, sodium, potassium, phosphorus, manganese, chlorine, and arsenic has been prepared and will be available about March 1. Two new standard samples of glasses containing boron, one 12 per cent. and the other 0.75 per cent. of B_2O_3 are being prepared.

Recently renewed standard samples are: (1) Cast Iron No. 4d which contains total carbon 2.66 per cent., graphite 2.00, combined carbon 0.66, manganese 0.894, phosphorus 0.081, sulphur 0.075, silicon 1.27, and copper 0.24; (2) Cast Iron No. 5f which contains: total carbon 2.25 per cent., graphite 1.52, combined carbon 0.72, manganese 0.755, phosphorus 0.243, sulphur 0.090, silicon 2.31, and copper 0.55; (3) Acid Open Hearth Steel No. 34a which contains: carbon 0.763 per cent., manganese 0.499, phosphorus 0.029, sulphur 0.026, silicon 0.276, copper 0.222, nickel 0.232, and chromium 0.275; and (4) Nickel Steel No. 33a which contains: carbon 0.366, manganese 0.700, phosphorus 0.037, sulphur 0.032, silicon 0.233, copper 0.114, nickel 3.48, and chromium 0.029.

In ordering standard samples, money orders, etc., should be made payable to the Bureau of Standards. If remittance does not accompany order, samples will be sent under Government frank by parcel post C.O.D. to addresses in the United States and its possessions. With the exception of Canada and Mexico, 20 cents postage must be added for every 300 grams of samples or fraction thereof. Payment for foreign orders should be by an international money order or by a check payable through the New York Clearing House or a bank in the United States.

A list of the standard samples issued to date may be had free on application to the Bureau of Standards by asking for "Supplement to Circular No. 25."

LIQUID SHRINKAGE OF ALLOYS.

THE American Foundrymen's Association, operating through its committee on cast iron and sub-committee on cast iron research, has established a Research Associateship at the

bureau, to continue for one year, for the study of methods of determining the liquid shrinkage of alloys.

The soundness of a casting depends, among other things, on its freedom from concealed piping or internal voids due to shrinkage, from trapped gas bubbles, and from shrinkage cracks. Three main factors are concerned in respect to the metal itself, as distinguished from the foundry practice, in securing freedom from these defects, i.e., fluidity, liquid shrinkage or change of volume between the liquid and the solid state, and solid shrinkage or change of volume between the freezing point and room temperature. Methods for the determination of the last property, solid shrinkage, are in fairly satisfactory shape, but those for the first two are not, as yet.

The bureau is already studying methods for determination of fluidity, and the establishment of this Research Associateship will allow an extension of the work to the study of liquid shrinkage.

The subject is of especial importance in the case of cast iron where the amount of liquid shrinkage seems to have a bearing on the suitability of different compositions of cast iron for different uses, but the American Foundrymen's Association is interested in the problem from the point of view of all other foundry alloys as well.

The object of the work is therefore not to collect masses of data on the liquid shrinkage of all the many alloys in use in the foundry, but rather to establish the suitability of some one or more methods for its determination in the various types of alloys. With reliable methods available the various branches of the foundry industry would be able to amass reliable and comparable data on the alloys in which they are interested.

IMPORTANCE OF TEMPERATURE AND HUMIDITY CONTROL IN RUBBER TESTING.

THE physical testing committee of the rubber division, American Chemical Society, through its research associate, F. E. Rupert, has conducted a series of tests at the bureau to determine the effect of temperature and humidity control in rubber testing.

This investigation involved several thousand tests, made

upon five rubber compounds under conditions in which temperature and humidity were varied during both preparation and testing. The compounds represent types of formulas in general use in the tire industry—a laboratory test compound, two high-grade gum tire carcass compounds, and two high-grade tread compounds. These formulas give an opportunity to observe the effect of humidity and temperature upon compounds of high and low rubber content and upon compounds containing two widely different types of organic accelerators, as well as varying amounts of common softeners.

The first part of the report deals with the effect of temperature and relative humidity subsequent to vulcanization but prior to testing. The temperatures used were 5, 15, 25, 35, and 45° C., and the relative humidities used at each of the above temperatures were 0, 20, 60, 80, and 100 per cent. Tests were made at each of these relative humidities at each temperature with each of five cures of the five compounds, thus providing for the effect of these variables upon both under and over cured materials.

This part of the investigation proved that variations in temperature which may occur from day to day in an uncontrolled testing room, may affect the physical tests to the same extent as a 25 to 40 per cent. change in time of cure. The relative humidity affects the results in only a minor degree.

The second part of the investigation, in which the same five compounds were used, dealt with the effect of temperature and relative humidity after mixing but prior to vulcanization. Only three cures of each compound were used, while the temperatures employed were 15, 25, and 35° C., and the relative humidities 10, 40, 70, and 100 per cent.

The results of this part of the investigation showed that variations in the absolute humidity of the room in which the unvulcanized rubber is stored between the time of mixing and the time of curing may affect the tensile strength and modulus of rubber compounds to as great a degree as does the temperature after vulcanization.

The effects upon the physical properties of vulcanized compounds produced by storing the raw ingredients under various humidities previous to mixing were also studied. No appreciable differences in the properties of the vulcanized

rubber were found, from which it was concluded that ordinary storage conditions are satisfactory for crude rubber compounding ingredients.

In an extension of this investigation, now in progress at the bureau, the effect of temperature and humidity, both prior to and subsequent to vulcanization, upon the resistance to abrasion, is being studied.

DIATOMACEOUS SILICA AS ADMIXTURE IN CONCRETE.

A PREVIOUS item dealing with this investigation appeared in Technical News Bulletin No. 141 (January, 1929). Other properties of the diatomaceous silicas are being studied as an aid in the development of specifications. Settling tests have been made on the representative samples according to one particular method of procedure which has been proposed. In this method, 2 gram samples of the different materials are placed in graduated cylinders, and sufficient water is added to make a total volume of 100 ml. at 20–30° C. The mixture is then shaken thoroughly, after which the cylinders are allowed to stand on a level space for 20 minutes and for 5 hours, respectively. The percentage of material in suspension in the 80 ml. nearest the top of the cylinders is then determined. The material in suspension in the top 80 ml. of water varied from 13.2 to 60.4 per cent. at the end of 20 minutes, and from 2.4 to 25.3 per cent. at the end of 5 hours.

It was noted that the diatomaceous silica swells when placed in lime water. A study of the volume of the resulting floc from the various representative samples may be an index of the fineness of subdivision and purity of the diatomaceous silica. It has been found that 2 grams of the various materials form flocs varying from about 12 to 35 ml. when placed in 100 ml. of saturated calcium hydroxide and allowed to settle 24 hours after an initial shaking of about 30 seconds. If the same procedure is followed, the measurements of the volume of the resulting floc from each diatomaceous silica may be checked to within 1 or 2 ml.

It has also been observed that diatomaceous silica will remove lime from a calcium hydroxide solution, from 1.15 g. CaO per liter (the approximate concentration of a saturated

solution at 30° C.) to about 0.07 g. CaO per liter. Increasing amounts of silica apparently do not further decrease this latter value. A study of the rate of this reaction has shown that different kinds of silicious materials decrease the concentration of the calcium hydroxide at different rates. The rate of the reaction has been measured by both chemical analyses of the resulting solutions and pH determinations, with very good agreement. It has been found possible to distinguish the purer grades of diatomaceous silicas (as determined from petrographic examination) from those containing considerable impurities, by this method, but to date it has not been found possible to differentiate the purer grades since the rate of decrease of concentration of the calcium hydroxide is so nearly the same with these latter materials. The time involved in obtaining these rates is too long to be of any value as a method for specifications.

CONSISTENCY MEASURING INSTRUMENTS FOR CALCINED GYPSUM.

AT the request of committee C–11 on gypsum of the American Society for Testing Materials, a study of the instruments for determining the standard testing consistency of calcined gypsum was undertaken. The instrument used at the present time is the Southard viscosimeter. It consists essentially of a circular plate 12 inches in diameter with a well 2 inches in diameter in the center, fitted with a false bottom. The well is filled with the mix to a depth of 2.5 inches and the mix forced out at the top by means of a screw under the false bottom. The mix is said to be of standard testing consistency when the spread of the pat is 9.7 cm. as read on the circular plate. The other instruments which were compared with the Southard viscosimeter were the Hammond and the modified Vicat apparatus. The Hammond apparatus consists essentially of a 2 × 4 inch cylinder which is filled with the mix and then raised vertically by means of a weight, through lever action, allowing the mix to spread out on a glass plate. The diameter of the pat is read on a scale beneath the glass plate. The modified Vicat instrument consists of a plunger of a fixed weight made of aluminum tubing. The end that penetrates the mix is 0.75 inches in diameter and 1.75 inches in length. The plunger is allowed to drop vertically into the mix con-

tained in a rubber ring mold, 7 cm. in diameter at the base, 6 cm. in diameter at the top and 4 cm. in depth. The penetration is determined by the drop of the plunger as read on a millimeter scale. The weight of the plunger may be varied by loading with shot.

A mix of gauging plaster was made up to standard testing consistency as determined by the Southard viscosimeter, and after many tests it was found that the most suitable penetration of the plunger of the Vicat was 30 mm., and this penetration was obtained when the plunger weighed 51 grams. A mix of gauging plaster of standard testing consistency when tested on the Hammond machine gave a spread of 4.1 in. It was found necessary to add retarder before making any test, or reproducible results could not be obtained.

The three instruments were then used to determine the standard testing consistency of 6 types of plaster and to determine which instrument was the most satisfactory. It was found that the three instruments did not check for all types of materials and that reproducible results could not be obtained for some types on any one instrument. The modified Vicat apparatus was found to be more sensitive to changes in consistency, easier to operate, and the penetration as shown by the drop of the plunger was more nearly proportional to the consistency than was the spread as shown by the Southard viscosimeter and Hammond machine.

FUNDAMENTAL STUDY OF GLAZE FIT.

As previously reported in Technical News Bulletins Nos. 125 and 128 (September and December, 1927) an investigation is being conducted at the Columbus branch of the bureau to determine the effect of the various oxides on the tensile strength, modulus of elasticity, and coefficient of expansion of glazes. Factors have been worked out for the various properties, based on the composition of the glazes as determined by chemical analysis.

The coefficient of expansion of the glazes increases slightly with temperature, but for the present work it is thought best to use the mean coefficient and express the effect of the various oxides as simple constants rather than as expressions such as

$a + bT$, where a and b are constants and T is the temperature in degrees C. The following tentative values for the oxides apply fairly well for the average linear coefficients over the range 20° C. to the lower critical temperature: Na_2O, 380; K_2O, 300; CaO, 150; BaO, 120; ZnO, 100; PbO, 75; Al_2O_3, 50; B_2O_3, 20; MgO, 20; all these values to be multiplied by 10^{-9}.

The factor for SiO_2 varies with the amount of SiO_2 present in the glaze, from 51 with 30 per cent. SiO_2 to 19 with 90 per cent. SiO_2. The first part of this work will be published in the near future.

Some work on the application of the data that have been collected on the physical properties has been started. The following subjects will be investigated: (1) resistance to thermal shock; (2) the effect on glaze fit of the upper critical temperature of the glaze and its position with respect to the alpha-beta inversion; and (3) the variation with temperatures of strain in a glaze attached to a body and its effect on crazing and shivering. The last subject will be investigated with the aid of a thermal microscope that has been built at the Columbus station.

A Study of the Fluctuations in the Amount of Ozone in the Atmosphere at Night. D. CHALONGE. (*Comptes Rendus*, June 25, 1928.) By photographing the ultra-violet spectrum of the sun and of the moon the author has determined the thickness of the layer of ozone in the upper atmosphere as often as possible on consecutive nights and days from October, 1927 to April, 1928. The measurements were made on the spectral region from 3100 to 3250 Å., where the absorption of ozone begins to be appreciable without being strong. Here unfortunately the absorption coefficient is less accurately known than for wave-lengths near 3000 Å. where others have worked in measuring the quantity of ozone. The feebleness of moonlight, however, prevented the use of the better known region.

The calculated depth of the ozone layer is never less at night than during neighboring days, indeed it is generally greater than by day, and it shows no seasonal variation, departing not greatly from its mean value of 3.35 mm. This conclusion is not as free of significance as might at first appear, for "From this it would follow that to explain the formation and fluctuations of ozone at high altitudes it is necessary to invoke other causes than solar ultra-violet radiation alone."

G. F. S.

Auroral Observations at the Sitka Magnetic Observatory, August, 1927 to June, 1928. F. P. ULRICH. (*Ter. Mag.*, Sept., 1928.) The station at Sitka got its time signals by radio from Annapolis, Mare Island and Honolulu. Reports were received by radio from several stations in Alaska and from Fort Yukon. Occurrences of the aurora were reported on 58 occasions and characterized thus, 34 faint, 21 bright and 3 brilliant. "The observations for this year seem to indicate that good (radio) reception is very much more apt to occur than poor reception during a bright or faint aurora. Aurora causes poor reception in cable-transmission, while in radio reception no difficulties are experienced in the majority of cases." For the past year the aurora was not accompanied by pulsations, draperies or coronas. Rays were seen 16 times. As the result of 901 observations on the relation of the state of the earth's magnetic field to the reception of radio messages it is stated that "in general the condition of the earth's magnetic field is no index of the way radio reception is received." G. F. S.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

EFFECT OF ENVIRONMENT ON PHOTOGRAPHIC SENSITIVITY. II. EFFECT ON CERTAIN SALTS.[1]

S. E. Sheppard and E. P. Wightman.

THE action of certain neutral salts on the formation of the latent image has been studied. Potassium citrate had no detectable effect, potassium chloride a slight effect upon developability, potassium bromide a very considerable depressing effect on the formation of the latent image. Contrary to the behavior with the visible image, acid silver nitrate was not found to accelerate latent image formation, at any rate with fairly high speed plates. The results are discussed in terms of the transfer of electrons from bromide ions to silver ions of the lattice, and it is suggested that the electrostatic field of the adsorbed double layer is a modifying factor of differing importance for visible and latent image formation.

THE ACTION OF FATTY ACIDS ON CELLULOSE.[2]

C. J. Malm and H. T. Clarke.

WHEN native cellulose is boiled with a lower fatty acid, esterification takes place which tends to a limit expressed by the formula: $C_{24}H_{39}O_{20}(CO.R)$. When hydrated or mercerized cellulose is treated in the same way, the limit is $C_6H_9O_5$-$(CO.R)$. From this it is concluded that the constitution of cellulose must be expressed as a multiple of the unit $C_{24}H_{39}O_{20}$.

* Communicated by the Director.

[1] Communication No. 349 from the Kodak Research Laboratories and published in *Phot. J.*, 69: 22. 1929.

[2] Communication No. 367 from the Kodak Research Laboratories and published in *J. Amer. Chem. Soc.* 51: 274. 1929.

Obsolescence vs. Depreciation. In a pamphlet issued by the American Institute of Steel Construction the results are presented of extensive studies of the loss in earning power of large modern constructions such as office buildings, hotels, apartment houses, and department stores. Through special facilities, many details were obtained of the vicissitudes that such buildings suffer in the feverish development of modern American cities. Shift of business centers is a not infrequent cause, but a more frequent one is the change in the details of construction and equipment. Every few years new methods of heating, lighting, refrigeration, ventilation, elevator service, fireproofing, and other accessorial features suffer modification. Tenants of the older types of building are more or less dissatisfied with their occupancy. The pamphlet, of course, distinguishes between obsolescence and depreciation. the latter being an inevitable result in all constructions. It is the fact that so many constructions from toys to railroad terminals get out-of-date long before wearing out that places so serious an economic burden on our modern life. The pamphlet deals only with large buildings, but it is worthy of note that in the matter of naval armament a similar and very costly condition arises and is constantly operative. Expensive ships become useless long before they wear out and they represent in their "scrapped" condition a mere trifle of the original cost. H. L.

High-Frequency Fluctuations in the Intensity of a Beam of Light. (*Proc. Phys. Soc.*, London, Vol. 40, Pt. 1.) A beam of light traversed the first of a pair of crossed nicol prisms but before reaching the second it passed through a piezo-electric crystal. When the crystal was unstressed no light emerged from the second nicol, but when the crystal was set in vibration by sending the current from a valve through a winding surrounding it light emerged from the system. This light was reflected from a polygonal drum and caught upon a screen. The variations in intensity due to the vibrations of the crystal manifested themselves by the appearance of bands 1.5 mm. apart. From this it was calculated that the frequency of the light beam was 168,800 cycles per sec., or about double the frequency of the crystal. G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

CARBON MONOXIDE CONTENT OF AUTOMOBILE ENGINE EXHAUST GASES NOT INCREASED BY USE OF ETHYL GASOLINE AS MOTOR FUEL.

THE use of gasoline containing ethyl fluid as an automobile engine fuel does not affect materially the percentage of carbon monoxide contained in the exhaust gases, the United States Bureau of Mines concludes, as the result of a series of tests conducted at its Pittsburgh Experiment Station.

Public interest in atmospheric pollution by automobile exhaust gas and in the ventilation of vehicular tunnels makes it desirable to ascertain whether the use of modern automobile fuels is tending to change the amount and composition of the products of combustion. The United States Bureau of Mines, in coöperation with the Ethyl Gasoline Corporation, has completed a series of tests to determine whether any significant difference exists in the carbon monoxide content of the exhaust gas produced by an internal-combustion engine when its fuel is changed from straight gasoline to the same gasoline containing ethyl fluid whose active ingredient is tetraethyl lead.

In the tests data was sought relative to the composition and amount of the gas produced by ordinary comparatively low-compression motors as well as by higher-compression motors in which distinct detonation occurred with straight gasoline, but which operated without detonation when using the same gasoline containing tetraethyl lead.

The gasoline used for these tests was all taken from the same refinery run to insure similar composition and characteristics. One portion was used as received from the refinery; to a second portion, ethyl fluid in the proportion of $2\frac{1}{4}$ c.c. of tetraethyl lead per gallon was added (this represented the antiknock value of standard ethyl gasoline as marketed); to a third portion was added ethyl fluid in the proportion of

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3 c.c. of tetraethyl lead per gallon. Tests were made with engine operating at full load and at three quarter load with various carburetor adjustments.

When the engine was operated at a fixed adjustment no significant change was found in the carbon monoxide content, nor in the content of any other constituent of the exhaust gas, upon changing the fuel supply of the engine from straight gasoline to gasoline containing tetraethyl lead (ethyl gasoline). This was true of both the tests in which a detonation was evident and those in which no detonation was audible. Also no significant difference in the amount of carbon monoxide per horse-power hour was noted.

However, if the spark was retarded to alleviate detonation during operation on straight gasoline the amount of carbon monoxide per horse-power hour was approximately 5 to 7 per cent. less for ethyl gasoline than for straight gasoline.

As to the effect of ethyl gasoline on health and safety the amounts of carbon monoxide produced by the engine, under any comparable operating condition, were the same for ethyl gasoline and straight gasoline.

PRODUCTION OF FERROMANGANESE FROM MANGANIFEROUS IRON ORES.

THE degree of dependence of the United States upon importations of manganese will be influenced to a great extent by the success achieved in obtaining ferromanganese from domestic low-grade reserves. For several years the United States Bureau of Mines has been investigating, at its North Central Experiment Station, Minneapolis, Minn., the possibilities of obtaining ferromanganese from manganiferous iron ores occurring as large deposits in Minnesota, New Mexico, and other localities. The main objective of this investigation is to determine the feasibility of recovering from these ores the manganese now used largely for its indirect effects. Although the indirect results from the use of these ores, such as aiding desulphurization in the blast furnace and producing more fluid slags in the open hearth, are useful functions, only a small portion of the manganese reaches the steel ingot, the greater part of it passing into irretrievable slag dumps.

The Bureau of Mines, in coöperation with the Minnesota School of Mines Experiment Station, demonstrated with a small 6-ton blast furnace and a small open-hearth furnace that it is feasible to produce from manganiferous iron ores, containing 5 to 10 per cent. manganese and averaging 7.5 per cent., a slag containing 40 to 50 per cent. manganese and permissible amounts of iron and phosphorus. Slags containing less than 10 per cent. silica have been made, but the time required is greater due to increased slag viscosity accompanying lower silica content. A larger experimental open-hearth furnace of the tilting type is nearing completion.

ABNORMALITY IN CASE-CARBURIZED STEEL.

Different results on depth of carbon penetration, grain size and uniformity of surface hardness are often found in carburized steels of essentially the same chemical analysis, and the term "abnormality of case-carburized steel" has been used to denote certain of these variations.

A study of this perplexing problem is being conducted at the Pittsburgh Experiment Station of the United States Bureau of Mines, Department of Commerce. It has been found that steels may show two distinct types of abnormality on carburization; grain size abnormality and structural abnormality. The first is usually due to the addition of certain elements to the steel and may be regulated by the elements added in the manufacture of the steel. For example, an increase in manganese tends to increase the grain size and the addition of vanadium refines the grain and the carburized piece will show grain size abnormality, i.e. smaller grains than are usually found. Heat treatments considerably affect this type of abnormality.

Structural abnormality has been found to be associated with either a high FeO content or with the presence of very small inclusions in the experimental steels made by the Bureau of Mines. Apparently as the inclusions become larger they affect structural abnormality less and less. Heat treatments do not affect this type of abnormality.

Further data on grain size and structural abnormality are being collected on samples prepared in a vacuum fusion

furnace under closely controlled conditions, and on steels deoxidized with various deoxidizers which give different types of inclusions.

A NEW TREND IN ORE DRESSING.

CRUSHING is the most costly step in all ore-dressing processes, observes the Department of Commerce. It is done in order to free the minerals comprising the ore from each other and to produce grains of a size within the recovering power of the process to be used. Costly fine grinding has heretofore been considered essential to flotation. Since there is considerable mineral loss in the slimes produced in such crushing, coarse sand flotation is being studied at the Moscow, Idaho, field station of the United States Bureau of Mines as a possible means of effecting economy. There are two main reasons why coarse flotation has been thought to hold little promise: First, there is a limit to the size of grains that flotation will lift. This limit is not exactly known, but has often been placed at 65 mesh. Coarser grains will float under favorable conditions. A second reason for favoring fine grinding is the difficulty of circulating coarse sand. The gravity-flow type of machine has overcome this objection. There is no need to float the largest mineral grains in a coarsely crushed pulp. They are ordinarily best recovered by gravity concentration.

The coarse sand flotation problem has been solved in the Michigan copper district. It embodies flotation of coarse sand followed by classification and table concentration. Flotation removes fine and intermediate-size mineral grains; the classifier overflow is tailing; the table recovers coarse mineral and middling, and rejects coarse tailing. A great metallurgical and economic advantage has been gained by this process. Experiments indicate that it applies equally effectively to ores of many other districts.

This process does not require flotation to recover unduly large mineral grains, nor tables to save the slime and fine mineral too small to feel the influence of gravity, nor does it require a classifier to deslime completely. The classifier functions only as a tailing-maker.

STUDY OF DEVICES FOR RECORDING PRESSURES DEVELOPED IN EXPLOSIONS.

Several different types of manometers have been used for recording the pressures developed during the course of mine explosions, says the United States Bureau of Mines, Department of Commerce. It is important that the results obtained with the different manometers be compared. Accordingly, the Pittsburgh Experiment Station of the Bureau of Mines undertook to determine the relative accuracy or degree of agreement of several commonly used types of manometers. The final comparison included the British Coal Dust (B.C.D.), Crosby, Illinois, Diederichs, and the Bureau of Mines instruments. The comparisons were made by connecting the manometers to a spherical explosion bomb in which mixtures of methane and air or hydrogen and air were exploded. The manometers were connected to the bomb in pairs, the Bureau of Mines instrument being common to all comparisons.

Although analysis and interpretation of the experimental data are not yet complete, it appears as a result of the intercomparisons that in general the Bureau of Mines manometer indicates a higher maximum pressure than any of the other instruments tested. This was not true in all tests with the B.C.D. instrument but was uniformly true for all tests with all the other manometers. The Bureau of Mines instrument attained maximum pressure in a shorter time after ignition of the gas than did any of the other manometers except the B.C.D. For the latter, the time to maximum pressure was sometimes greater and sometimes less than for the Bureau of Mines instrument.

The Bureau of Mines instrument showed more favorable characteristics as regards elastic hysteresis than did the other instruments. In the test using hydrogen-air mixtures, pronounced vibrations appear in the time-pressure records. These are believed to be vibrations of the diaphragms caused by the suddenness of the explosions, rather than by stationary waves set up in the explosion bomb, although the latter appears as a possibility. Initially the vibrations were of approximately the same frequency as that of the experimentally determined free-period vibrations of the respective instruments; but the frequency invariably decreased as the pressure decreased and the vibration died away. The frequency finally reached about one-half the original frequency.

The Index of Refraction of Glass for X-Rays of Long Wave-length. J. THIBAUD. (*Comptes Rendus*, July 23, 1928.) In previous papers reporting their spectroscopic investigations of very soft X-rays Thibaud and Soltan directed attention to the seeming dependence of the wave-lengths of the same rays upon the method used to measure them. The length got by the use of ruled diffraction gratings was not the same as that obtained from diffraction in crystals. They explained the difference as due to refraction in the interior of the crystal and drew the conclusion that there is a real index of refraction of value less than unity, when X-rays of long wave-length pass from a vacuum into a material medium. Their measurements further indicated, in accordance with the Drude-Lorentz theory of dispersion, that the quantity by which the index is less than unity increases with the square of the wave-length. The object of the present investigation is to calculate the index of refraction of glass from the measured angle of total reflection. When an X-ray of considerable wave-length falls on a reflecting surface of glass, it is totally reflected provided that the angle between the direction of the ray and the surface does not exceed in value a limiting angle, θ. When θ is known the index of refraction μ is calculated by the formula, $Q = \sqrt{2(1-\mu)}$.

To determine the limiting angle θ a vacuum grating spectrograph was utilized. Different monochromatic X-rays fell on a glass grating and photographic registration of the diffracted rays showed that their intensity diminished progressively as the angle between the rays and the plane of the grating approached the angle θ. Visual perception of the varying intensities was aided by the fact that the spectra sometimes extended to the seventh order.

In the following table of results λ, the wave-length is given in Angstrom units; θ, the limiting angle, in radians and δ is the number that must be subtracted from 1 to get the refractive index.

	Ordinary X-Rays	X-Rays of Great Wave-Length			
λ	1.5	20.	44.9	54.9	65.
θ	.004	.031	.051	.061	.078
δ	.000007	.00048	.0013	.00186	.00305

The limiting angle for the wave-length 1.5 is 21 minutes, for 45 Å. it is 3° and for 65 Å. it is 4° 30′. For this last wave-length the index of refraction is 1 − .00305 or .99695. The observed value of the limiting angle does not grow with increase of wave-length as rapidly as theory requires it to grow. G. F. S.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, FEBRUARY 20, 1929.

The stated monthly meeting was called to order at eight-fifteen by Mr. C. C. Tutwiler, Second Vice-President, in the absence of the President.

The Secretary announced that the minutes of the January meeting had been published in full in the Journal of The Franklin Institute for February, and moved that the minutes be approved as printed. The motion was adopted unanimously.

For the Committee on Membership the Secretary reported that since the beginning of the new year, the following additions had been made to our membership: two Life members; eight Resident members; five Non-Resident members; 1 Student member. He announced with great regret the deaths of eight members during the same period.

The Secretary stated that this was the meeting at which the Institute Committees for the year 1929 should be announced and said that the President of the Institute, Mr. Hayward, had appointed, in accordance with the By-laws, the following Committees of the Institute:

Committee on Library

C. W. Bates, Chairman
H. J. M. Creighton
W. H. Fulweiler
Clarence A. Hall
Joseph S. Hepburn
George A. Hoadley
Lionel F. Levy
Malcolm Lloyd, Jr.
M. M. Price
George F. Stradling

Committee on Meetings

Howard McClenahan, Chairman
James Barnes
George S. Crampton
T. G. Delbridge
Arthur W. Goodspeed
Charles Penrose
George D. Rosengarten
Coleman Sellers, 3d
W. C. Wagner
W. Chattin Wetherill

Committee on Museum

Hugo Bilgrim, Chairman
G. H. Benzon, Jr.
Arthur L. Church
Theobald F. Clark
George A. Hoadley
John J. L. Houston
Henry Leffmann
Frederic Palmer, Jr.
H. H. Quimby
William O. Sawtelle

The Secretary stated further that the following persons had been elected to membership in the Committee on Science and the Arts, for a period of three years:

Henry B. Allen
Clifford W. Bates
Hugo Bilgram
William L. Brown, 3d
Edward L. Clark
Theobald F. Clark
Theodore K. Cleveland
Thomas D. Cope
William G. Ellis
W. H. Kavanaugh
C. H. Masland, 2d
Frederic Palmer, Jr.
Charles Penrose
M. M. Price
James S. Rogers
Samuel Shoemaker
F. R. Wadleigh
Robert L. Wood
Winthrop R. Wright

He also announced that Dr. Thomas D. Cope, Department of Physics, University of Pennsylvania, had been elected Chairman of the Committee on Science and the Arts for the present year.

There being no further business, the Chairman of the meeting introduced as the speaker of the evening Mr. A. R. Stevenson, Jr., of the General Electric Company, Schenectady, N. Y., who spoke on "Refrigeration in Theory and Practice."

The paper was most interesting and admirably delivered. It was followed by some discussion, after which the meeting closed with a vote of hearty thanks to Mr. Stevenson for his valuable lecture.

HOWARD MCCLENAHAN,
Secretary

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, February 6, 1929.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, February 6, 1929.

DOCTOR GEORGE S. CRAMPTON *in the Chair.*

The Chairman announced the reelection by the Board of Managers of seventeen members of the Committee to serve for three years and the election of the following new members to serve for three years:

Doctor Theodore K. Cleveland
Mr. Samuel Shoemaker

The Special Committee on Nomination of a Chairman for the ensuing year reported as its choice Doctor Thomas D. Cope. Doctor Cope was unanimously elected and took the Chair.

The following reports were presented for final action:

No. 2840: Klydonograph.

This device may be called a wave writer since it automatically makes a graphic record of information concerning the electrical surges that take place on extended transmission lines. This information includes the polarity of the surge, its magnitude and the steepness of its wave front, the interpretation of the record giving the desired information.

The fundamental experiments that have led to the development of the klydonograph were made by Doctor Lichtenburg in 1777 by passing a condenser discharge across a spark gap onto a terminal in contact with an insulating plate resting upon a grounded metal plate. A powder, sifted upon the upper plate, would show figures characteristic of the discharge and these were known as Lichtenburg figures.

If the discharges take place across the film surface of a photographic plate or film the record is made on its surface and can be used for reproduction and study.

Mr. J. F. Peters of the Transformer Engineering Department of the Westinghouse Company has standardized the form of instrument used and by controlling the conditions under which the figures are obtained, making a comparative study of these figures and interpreting their forms, has made a valuable addition to the knowledge of these surges and their results.

The most recent form of instrument is provided with a clock mechanism by which a roll of sensitized film is moved at a known rate, thus providing means to secure permanent records for future study.

The award of the Edward Longstreth Medal was recommended to Mr. John F. Peters, of Swissvale, Pennsylvania, "In consideration of his successful development of a practical instrument for the recording of voltage surges on transmission lines."

No. 2879: Temperature Control for Gas Furnaces.

The purpose of this device is to enable a gas furnace to control its own temperature automatically. This is done by utilizing the minute current generated in a thermocouple as the first step in operating the gas and air valves that supply its fuel.

The current from the thermocouple passes around a pivoted rotating coil which carries a needle and controls its position, the reading of the needle indicating the temperature.

A vertically moving contacting device that moves up and down in the path of the needle at a predetermined temperature is provided and when this makes contact with the needle, mechanical devices are set in motion that operate the valves controlling the feeding of the mixed air and gas into the furnace thus obtaining the desired temperature. The award of the Certificate of Merit to Mr. George Machlet, of the American Gas Furnace Company, of Elizabeth, New Jersey, was recommended by the Sub-Committee, "In consideration of his pioneer work in perfecting the automatic temperature control for gas fired furnaces."

No. 2885: Work of Sir James C. Irvine in Chemistry.

The few years that have elapsed since the beginning of the present century have seen a notable advance in the science of chemistry and in the practical application of the results of these advances.

Among the brilliant workers in an especial field is Sir James C. Irvine, the Principal of the University of St. Andrews, Scotland, in carbohydrate chemistry. His work on the structural chemistry of the carbohydrates involved the difficult task of separating from each other a series of substances that were closely allied and that had resisted many attempts at separation.

In the beginning of his work he undertook the methylation of various mem-

bers of the sugar group and from a study of the simpler methylated derivatives he was able to determine the structure of the parent compound.

"In 1910, an entirely fresh field was entered upon in Irvine's laboratory, where, by means of a new method of methylation, methyl radicals were introduced into cellulose and starch, and Irvine succeeded in attaining a deeper insight into the structure of the molecules of these very complex substances."

"Irvine's work on the methylation of carbohydrates resulted in the gradual accumulation of a mass of evidence which led to the discovery of a new class of sugars—the gamma sugars, in which the oxygen ring is displaced from the normal, stable position.

"In consideration of his brilliant researches in the field of carbohydrate chemistry, the award of the Elliott Cresson Medal was recommended to Sir James C. Irvine, of St. Andrews, Scotland."

The Franklin Medal—Doctor James Barnes, Chairman.

No. 2903: To Mr. Emile Berliner, Inventor, of Washington, D. C.

"In recognition of a life-work in successful invention: the discovery of the electrical characteristics of the loose contact and application of them to telephony in the microphone, which he originated; development of the talking machine which uses a disc upon which the sound is recorded by a laterally cut groove; and, in recent years, his contributions to the production of proper acoustical qualities in architectural structures."

No. 2904: To Doctor Charles Thomson Rees Wilson, Jacksonian Professor of Natural Philosophy, Cambridge University, England.

"In recognition of his numerous pioneer contributions to atomic physics, especially for his studies of condensation nuclei and his development of a method of photographing their tracks and for the vital importance of these studies to our knowledge of atomic structure and quantum mechanics."

The following report was presented for first reading:

No. 2901: Self-Aligning Coupling.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, February 13, 1929.*)

LIFE.

MR. MALCOLM LLOYD HAYWARD, Student, Adirondack-Florida School, Onchiota, N. Y.

MR. NATHAN HAYWARD, JR., Student, E 31 McKindock, Harvard University, Cambridge, Mass.

RESIDENT.

MR. SOLOMON D. BENOLIEL, Electro-Chemical Engineer, International Chemical Company, Philadelphia, Pa. For mailing: c/o International Chemical Company, 2628 North Mascher Street, Philadelphia, Pa.

MR. LOUIS S. CLARKE, Consulting Engineer, c/o The Autocar Company, Ardmore, Pa.

MR. EDWARD S. W. FARNUM, JR., Attorney, 1528 Land Title Building, Philadelphia, Pa. For mailing: 101 West Graver's Lane, Philadelphia, Pa.

MR. OTHMAR KARL MARTI, Chief Engineer, American Brown Boveri Electrical Corporation, Camden, N. J.

MR. JACKSON BORNMAN RAIGUEL, Chemical Engineer, Franklin Sugar Refining Company, Philadelphia, Pa. For mailing: 105 Walnut Street, Jenkintown, Pa.

DR. OWEN LOUIS SHINN, Professor of Applied Chemistry, Acting Director of Laboratory, Harrison Laboratory, University of Pennsylvania, Philadelphia, Pa.

DR. ENOS E. WITMER, Assistant Professor of Physics, Randal Morgan Laboratory of Physics, University of Pennsylvania, Philadelphia, Pa.

NON-RESIDENT.

DR. HARVEY NATHANIEL DAVIS, Teacher, President, Stevens Institute of Technology, Hoboken, N. J.

MR. JOSEPH E. KUCHER, Consulting Engineer, 10 West 170th Street, New York City. For mailing: 314 Claremont Avenue, Jersey City, N. J.

MR. KELVIN SMITH, Engineer, The France Manufacturing Company, Cleveland, Ohio. For mailing: 3077 Huntington Road, Cleveland, Ohio.

CHANGES OF ADDRESS.

MR. W. R. ARMSTRONG, c/o Merck and Company, Inc., 916 Parrish Street, Philadelphia, Pa.

MR. WILLIAM L. AUSTIN, Room 2607, 123 South Broad Street, Philadelphia, Pa.

MR. ALFRED E. BLAKE, 1511 Dickinson Road, West Brookline, Upper Darby P.O., Pa.

MR. BEAUVEAU BORIE, JR., Bell's Mill Road, Chestnut Hill, Philadelphia, Pa.

CAPTAIN HIRAM B. ELY, Room 1051, Bell Telephone Laboratories, 463 West Street, New York City.

MR. H. LINWOOD GODFREY, Packard Building, Fifteenth and Chestnut Streets, Philadelphia, Pa. c/o C. N. Anderson, Patent Attorney.

MR. JOHN M. HAMMOND, The Phototechnical Laboratory, Inc., 6 "N" Street, Northeast, Washington, D. C.

MR. DANIEL O. LANDIS, 612 North Thirty-fourth Street, Philadelphia, Pa.

MR. H. W. LILLEBRIDGE, 5015 Copley Road, Germantown, Philadelphia, Pa.

MR. PERCY S. LYON, c/o Hall Electric Heating Company, 1429 Walnut Street, Philadelphia, Pa.

MR. CHARLES W. MOORE, 350 High Street, Sharon Hill, Pa.

MR. GEORGE A. ORROK, 52 Vanderbilt Avenue, New York City.

MR. RODOLPHO ORTENBLAD, The Rio de Janeiro Tramway Light and Power Company, Ltd., Caixa de Correio 571, Rio de Janeiro, Brazil.

DR. A. D. POWER, Research Laboratory, Westinghouse Lamp Company, Bloomfield, N. J.

MR. BENJAMIN WILEY SANDS, 411 South Pioneer Street, Lyons, Kansas.

MR. BIRCHARD TAYLOR, Harper and Taylor, Inc., 225 South Fifteenth Street, Philadelphia, Pa.

MR. WARREN P. VALENTINE, 154 North 11th Street, Philadelphia, Pa.

NECROLOGY.

Mr. A. J. Bradley, New York City.
Mr. Thomas Duncan, Lafayette, Indiana.
Mr. James Elverson, Jr., Philadelphia, Pa
Mr. Harold A. Freeman, Philadelphia, Pa.
Dr. C. C. Harrison, Philadelphia, Pa.
Mr. A. M. Randolph, Warrenton, Va.
Mr. J. Bunford Samuel, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

AMBRONN, RICHARD. Elements of Geophysics as Applied to Explorations for Minerals, Oil and Gas. 1928.

American Electrochemical Society. Transactions. Volume 53. 1928.

American Foundrymen's Association. Transactions. Volume 36. 1928.

American Society For Testing Materials. Proceedings: Thirty-first annual meeting. Volume 28, parts 1 and 2. Two volumes. 1928.

BENTON, JOHN ROBERT. An Introductory Textbook of Electrical Engineering 1928.

BIRTWISTLE, GEORGE. The New Quantum Mechanics. 1928.

BLASDALE, WALTER C. The Fundamentals of Quantitative Analysis. Third edition. 1928.

BROGLIE, MAURICE DE AND LOUIS DE. Introduction à la Physique des Rayons X et Gamma. 1928.

Bulletin Almanac and Year Book. 1929.

CROWTHER, JAMES ARNOLD. Ions, Electrons, and Ionizing Radiations. Fourth edition. No date.

CUNNINGHAM, BRYSSON. Port Studies. 1928.

DARLING, CHARLES S. Exhaust Steam Engineering. 1929.

DÉRIAZ, WILLIAM. Les Mesures de Températures Courantes. 1927.

DINSDALE, ALFRED. Television. 1928.

ECKEL, EDWIN C. Cements, Limes and Plasters. Third edition. 1928.

EDDINGTON, A. S. The Nature of the Physical World. 1928.

EDISON, OSKAR E., AND FERRIS W. NORRIS. Electrical Engineering Laboratory Practice. 1928.

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GEIGER, H., AND KARL SCHEEL, editors. Handbuch der Physik. Band XX: Licht als Wellenbewegung. 1928.

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HAAS, ARTHUR. The World of Atoms. 1928.

HAMMER, WILLIAM O. Illustrated Guide and Descriptions of Photographic Inter-Lens Shutters. 1917.

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HOUGH, ROMEYN B. The American Woods. With text by Marjorie G. Hough. Part 14. 1928.

KEFFER, ROBERT, AND CHARLES L. MCNEIL. Methods in Non-Ferrous Metallurgical Analysis. 1928.

KEINATH, GEORG. Die Technik elektrischer Messgeräte. Dritte, vollständig umgearbeitete Auflage. Two volumes. 1928.

KENDALL, EDWARD C. Thyroxine. 1929.

LITTLE, ARTHUR D. The Handwriting on the Wall. 1928.

MANTELL, C. L. Industrial Carbon. 1928.

MASON, MAX. Physical Exploration for Ores. 1927.

METCALF, LEONARD, AND HARRISON P. EDDY. American Sewerage Practice. Volume one, second edition. 1928.

OSGOOD, WILLIAM F. Advanced Calculus. 1928.

REED, EVERETT L. Photomicrographs of Iron and Steel. 1929.

ROMMEL, GEORGE M. Farm Products in Industry. 1928.

SACKETT, ROBERT LEMUEL. The Engineer: His Work and His Education. 1928.

SHAPLEY, HARLOW, AND HELEN E. HOWARTH. A Source Book in Astronomy. 1929.

SHAW, SIR NAPIER. Manual of Meteorology. Volumes one and two. 1926–1928.

STANISLAUS, I. V. STANLEY, AND P. B. MEERBOTT. American Soap Maker's Guide. Third edition. 1928.

STERLING, GEORGE E. The Radio Manual. 1928.

TAYLOR, FREDERICK W., S. E. THOMPSON, AND EDWARD SMULSKI. Concrete Plain and Reinforced. Fourth edition, volumes one and two. 1925–1928.

TIMOSHENKO, S. Vibration Problems in Engineering. 1928.

United States Patent Office. Index of Trade Marks Issued in 1927. 1928.

WALDSCHMIDT-LEITZ, ERNST. Enzyme Actions and Properties. 1929.

Wer ist's. IX Ausgabe. 1928.

Who's Who 1929.

WIEN, W., AND F. HARMS, editors. Handbuch der Experimentalphysik. Band 25, 1 Teil: Geophysik 1 Teil. 1928.

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BOOK REVIEWS

NATIONAL ADVISORY COMMITTEE FOR AËRONAUTICS.

Report No. 293. Two Practical Methods for the Calculation of the Horizontal Tail Area Necessary for a Statically Stable Airplane, by Walter S. Diehl. 20 pages, illustrations, quarto. Washington, Government Printing Office, 1928. Price, ten cents.

This report is concerned with the problem of calculation of the horizontal tail area necessary to give a statically stable airplane. Two entirely different methods are developed, and reduced to simple formulas easily applied to any design combination. Detailed instructions are given for use of the formulas,

and all calculations are illustrated by examples. The relative importance of the factors influencing stability is also shown.

Report No. 295. The Variation in Engine Power with Altitude Determined from Measurements in Flight with a Hub Dynamometer, by W. D. Gove. 12pages, illustrations, quarto. Washington, Government Printing Office, 1928. Price ten cents.

The rate of change in power of aircraft engines with altitude has been the subject of considerable discussion. Only a small amount of data from direct measurements of the power delivered by airplane engines during flight, however, has been published. This report presents the results of direct measurements of the power delivered by a Liberty 12 airplane engine taken with a hub dynanometer at standard altitudes from zero to 13,000 feet. Six flights were made with the engine installed in a modified DH-4 airplane. The tests were conducted at the Langley Memorial Aëronautical Laboratory of the National Advisory Committee for Aëronautics.

The experimental relation of brake horsepower to altitude is compared with two theoretical relations and with the experimental results, for a second Liberty 12 engine, given in N. A. C. A. Technical Report No. 252. The rate of change in power with altitude of a third Liberty engine, measured with a calibrated propeller, is also given for comparison.

The data presented substantiate the theoretical relation of brake horsepower to altitude based on the correction of ground level indicated horsepower for changes in atmospheric temperature and pressure with the subsequent deduction of friction horsepower corrected for altitude. The equation for this relation is

$$B\cdot\mathrm{HP}_a = B\cdot\mathrm{HP}_o\left[\left(\frac{P_o}{P_a}\right)\left(\frac{T_a}{T_o}\right)^{1/2}\left(1+\frac{\lambda-\lambda n}{n}\right)-\left(\frac{\lambda-\lambda n}{n}\right)\right],$$

where P is the absolute atmospheric pressure, T is the absolute temperature, n is the mechanical efficiency of the engine at sea level and λ is the ratio of mechanical friction to friction horsepower at sea level. The subscripts o and a denote sea level and altitude conditions, respectively. R.

THE RADIO MANUAL. For radio engineers, inspectors, students, operators and radio fans. By George E. Sterling, Radio Inspector, Radio Division, U. S. Department of Commerce, member, Institute of Radio Engineers. Edited by Robert S. Kruse, B.S., formerly Technical Editor Q. S. T., Magazine of American Radio Relay League; consultant for development of short wave devices, technical editor and writer. vii–666 pages, illustrations, 8vo, fabricoid. New York, D. Van Nostrand Company, Inc., 1928. Price, $6.

If radio has yet far to go with the realization in usable form of the present aspirations of research laboratories it has certainly already attained an important position in electrical science and has given rise to a large and thriving industry. The literature of the subject has naturally had an equally rapid growth. The present volume which is written by authors, whose activities in the field are administrative and authoritative as well as technical, is for that reason of particular interest to the reader in search of definite information. The work is intended to serve as a guide and text-book to those who expect to enter the radio profession as engineer, inspector, commercial or amateur operator. Besides the purely

physical features of the subject which are treated arithmetically, formidable mathematical formulas being conspicuously absent, code matters issued by the International Radiotelegraphic Convention and by the Federal Radio Commission and the like are included. Particular attention is directed to the authoritative sources of information included. A bibliography of such references, which appears to have been omitted, would be decidedly helpful in a work of reference of this kind. It is of interest to note that the work appeared in October 1928 and reached its third printing in December. The full and well-illustrated treatment and the authoritative sources of the subject-matter should insure for the work a continuation of a large initial demand.

LUCIEN E. PICOLET.

AN INTRODUCTORY TEXTBOOK OF ELECTRICAL ENGINEERING. By John Robert Benton, Professor of Physics and Electrical Engineering in the University of Florida. xi–347 pages, illustrations, 8vo, cloth. Boston, Ginn and Company, 1928. Price, $3.60.

Between the royal road of superficiality and an exhaustive study of a subject, there must be some middle course of procedure which permits a satisfactory survey within the time limits imposed by harmonious relation to the other subjects of the college course. This text, which covers practically the entire field of electric generators and motors, is designed for a purpose of that kind. The mechanical specialist will there find in compact form a resumé of the principles of electrodynamics, their development and application to well-known types of power appliances in common use. The electrical specialist may cover the same ground with fewer omissions and then proceed to other works to which this one will serve as an introduction. As is proper in a text, a copious collection of examples accompanies each chapter. Some knowledge of college physics and elementary calculus are essential. Numerous clear and effective diagrams and half-tones of actual machines add materially to this satisfactory presentation of the principles of electrical machinery. The volume is one of the Engineering Series edited under the supervision of Andrey A. Potter, Eng. D., Dean of the School of Engineering and Director Engineering Experiment Station, Purdue University. L. E. P.

ELECTRICAL ENGINEERING LABORATORY PRACTICE. By Oskar E. Edison, E.E., Associate Professor of Electrical Engineering in the University of Nebraska, and Ferris W. Norris, E.E., Associate Professor of Electrical Engineering in the University of Nebraska. ix—276 pages, illustrations, 8vo, cloth. Boston, Ginn and Company, 1928. Price, $2.80.

Of the same series as the preceding textbook, this work, which deals with the laboratory operations of electrical measurements and testing of electrical machinery, may properly be regarded a companion volume. The experiments adequately cover the subject-matter of the preceding work and of course any other work covering the same ground, and each one is described under the headings of "object," "reference," "apparatus," and "method" with such additional directions as may be demanded by the nature of the experiment. These directions are definite enough to properly guide the student without such amplification as might deprive him of the educational value of thinking for himself in carrying out the details of an experiment. Numerous well-executed diagrams of circuits, apparatus, and performance curves accompany the text.

LUCIEN E. PICOLET.

THE ENGINEER, HIS WORKS AND HIS EDUCATION. By ROBERT LEMUEL SACKETT, C.E., Dean of Engineering, The Pennsylvania State College. vii–196 pages, illustrations, 20 x 13.5 cm., cloth. Boston, Ginn and Company, 1928. Price, $1.40.

The accelerating pace of achievement in science and industry during the last three decades has brought about an enormous expansion of activities in every phase of economic effort. Whether the rapid progression of this change is for the better or the worse, the new conditions which accompany it must be met. Engineering education has been notably affected by this expansion and the task of the professional schools to provide facilities to meet a corresponding demand for technical education is one of considerable magnitude, and not the least of the problems encountered are those of a pedagogic character incident to large-scale operation. The training of large numbers of individuals in technical subjects demands careful planning to insure an efficient utilization of the time allotted to a college course. Again technical students are recruited from widely diversified individual types. One student, prior to taking an engineering course, may have had contact with an environment of engineering activity and so possesses an adequate conception of what he is undertaking; another in a different environment may have an altogether faulty notion of the real objectives of his course of study.

Professor Sackett provides a deeply interesting and informative account of what a prospective candidate for entrance into a school of engineering should know concerning the profession apart from the purely academic entrance requirements as well as the personal characteristics which should determine the expediency of the undertaking. All such questions are presented and discussed in a convincing manner. Modern courses and their characteristics are described at length from which constructive information may be derived by a reader whose conceptions of their objects and functioning may be faulty. An appendix contains short biographies of famous engineers.

A college course cannot be undone if it proves ill-advised nor, generally, can it be done over. This book provides the stitch in time.

LUCIEN E. PICOLET.

INTRODUCTION A LA PHYSIQUE DES RAYONS X ET GAMMA. Par MM. Maurice deBroglie, Membre de l'Institut, et Louis deBroglie, Docteur ès Sciences. v–201 pages, illustrations, 8vo, paper. Paris, Gauthier-Villars et Cie, 1928. Price, 50 francs.

The mode of conquest of any new principle in physical science may be likened to a succession of assaults upon a stronghold each one of which discloses a better method of attack. Ever since the discovery of x-rays, which greatly stimulated the efforts of physicists in the study of radiation phenomena, the keenest minds of the realm of physical science have unremittingly pursued the quest of a solution of the characteristics of these rays and others of recent discovery. The deBroglies have been active contributors in this field, and with the accumulated wealth of data from many other important sources, they describe at length in this work the salient properties of x-rays and gamma-rays more particularly in their relation to a profound modification of the classic conceptions of the structure of light.

Before making a detailed examination of x-rays and gamma rays, the authors

make a general survey of their nature and point to experimental evidence of their periodic character, again to other indications of their corpuscular nature and then to general views of their probable actual nature. The detailed examinations begin with a consideration of the atomic theory of Bohr and then proceeds to its application to the x-ray spectrum. Among the topics which follow are: the photo-electric effect, rays of very short and very long wave-length, diffraction by the use of crystals, physical optics of x-rays, and thermodynamic and astrophysical considerations. Two postscripts are added, the one on the possible existence of a phenomenon analogous to that of Laue of electrons impinging upon a crystal, the other, on the magnetic electron and the formula of Sommerfeld. The views there expressed if verified, the authors believe, will effect a rational coördination of conflicting views on matter and radiation.

The obvious value of a discussion of x- and gamma-radiations in harmony with modern ideas of the ultimate structure of matter by these celebrated authors will surely bespeak for the work a wide circulation.

L. E. P.

THYROXINE. By Edward C. Kendall, M.C., Ph.D., D.Sc. 265 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929. Price, $5.50.

The nature and function of the ductless glands were for many years the bugbear of physiology. Naturally, physicians were strongly inclined to the view that such a definite series of organs must have positive functions but information was not forthcoming. The obscurity gave rise to a reaction by which the functions were the subject of humor. The incident, which is claimed to have happened in every class in every medical school and happened in none, typified the hopeless, ness of the case. "What is the function of the spleen?" said the Professor- "Doctor," said the student, "I knew that last night and I have forgotten it." "The most unfortunate incident in the history of physiology. Only one man knew the function of the spleen and he forgot it."

Seriously, however, the data that have been accumulated by patient investigation during the last quarter century have been of tremendous importance in the realms of physiology, pathology and therapeutics. The volume in hand (the 47th of the series of American Chemical Society Monographs) is devoted entirely to the important proximate principle of the thyroid gland, and is the result of long and careful laboratory work by the author with comprehensive search of the extensive literature. The subject is presented from the view-point of the chemist, especially directed to correlating the activity of the thyroid gland. Much still remains to be elucidated, but the author shows that the clinical and physiologic results are clear and quantitive. Naturally, in the midst of the early ignorance and the primary investigations many theories were suggested, but most of these have lost value and the few remaining are restricted in application.

Physical chemistry has been brought into action, so that while the problems of the gland are far from being wholly solved, the investigations from the clinical and physiologic points of view are strictly rational and guided by satisfactory principles.

To the trained investigator in this field the problems are attractive; thyroxine, the author says, bridges the gap between living protoplasm and temperament, or what we may more definitely call personality. The study of the substance is carried into the most difficult of all departments of medicine, mental aberrations.

It is not yet possible to say if the action is catalytic. It is even suggested that it may be a still more remote action, that is, controlling catalytic (enzymic) action. The complexity of chemistry increases steadily. One discovery opens up the duty and opportunity of making more. We might modify Milton's language and say: "In the lowest deep, a lower deep still threatening to devour us opens wide."

The author concludes the preface with these words: "There are many questions left unanswered; time will bring many additions and possibly many alterations."

HENRY LEFFMANN.

A TEXTBOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.S., Ph.D., F.I.C., Carnegie Gold Medallist. Volume XI, Organo-metallic Compounds, Part I, Derivatives of the Elements of Groups I to IV, by Archibald Edwin Goddard, M.Sc. (B'ham), A.I.C., and Dorothy Goddard, M.Sc. (B'ham). 417 pages, illustrations, 8vo. London, Charles Griffin & Company, Ltd., and Philadelphia, J. B. Lippincott Company, 1928. Price, $14.

The list of elements included within this volume stops short of the element from which the first organo-metallic compound was obtained. Arsenic was the first element to be comprised in an organic group. It was about the time of the American revolution that Louis Claude Cadet de Gassicourt, a French apothecary, distilled a mixture of an alkali acetate and arsenous oxide and obtained the fuming liquid still known by his name. This is a mixture of several substances, principally dimethylarsin oxide, commonly called kakodylic (cacodylic) oxide. The composition of the principal substance and of many of its derivatives was elucidated by Bunsen in a comprehensive and painstaking research, which is a model of procedure in chemistry. He lost an eye by an explosion during the work. Arsenic belongs to the fifth group of the periodic system and, therefore, the kakodylic derivatives do not appear in the book. A future volume will cover the subject, but very little is available in supplement of Bunsen's work. Kakodylic acid has found some applications in medicine from the fact that the arsenic is in a position in the molecule that renders it less toxic than the familiar forms.

The volume in hand contains many compounds that are more familiar than the kakodyls, especially those of mercury, tin and lead. About one hundred and fifty pages are devoted to mercury compounds. Lead receives notice for about a score of pages, among which is, of course, noted the lead tetrethyl, now so well known and so much discussed as an "anti-knock for motors."

Methods for the preparation of *key* compounds are given in detail so that the book may be used as a treatise on practical chemistry. The substances described are limited to those in which the second element is linked directly to carbon, excluding those in which it is linked through oxygen or nitrogen as well as double compounds of organic substances with inorganic salts. In spite of these limitations about 2,300 compounds are described. In view of the wide field covered no systematic attempt has been made to discuss theoretical aspects, but the large number of substances described and formulated will materially assist those who desire to make extensive comparisons. Physical constants of a large number of compounds have been set forth in an appendix. Throughout the book greater attention has been paid to physical properties generally than is usual in this type of book.

A large proportion of the organo-metallic substances are highly poisonous.

Many of them are volatile which increases the danger. Reference has been made above to the poisonous fumes of arsendimethyl oxide. Bunsen found kakodyl cyanide to be one of the most poisonous compounds then known. Mercuric dimethyl and mercuric diethyl caused several deaths among those working with them many years ago, and gave rise to very severe criticism of Dr. Frankland in connection with the case. In the early days of the use of tetrethyl lead, numerous cases of poisoning occurred.

The book represents an enormous amount of patient labor and searching the literature and compiling the vast amount of data already accumulated and also embodies the authors' own extensive investigations. Women authors have appeared more frequently in this series than is usual in the literature of chemistry. A great deal of praise is due to the authors for their work, but the reviewer cannot refrain from objecting to the form of the subject-index. This is arranged under the individual metals as they occur in the periodic system. This seems to be classification "run amuck." An index is a purely mechanical aid to finding text relating to a given subject. No attempt should be made to adapt it as either a table of contents (as the French do so frequently) or to serve the purpose of key to any theoretical or practical relationship. The man who catalogued "Lead compounds" and followed this entry by "Ditto, Kindly Light" was on the right track.

HENRY LEFFMANN.

SPEECH AND HEARING. By Harvey Fletcher, Ph.D., Acoustical Research Director, Bell Telephone Laboratories, Inc., with an introduction by H. D. Arnold, Ph.D., Director of Research, Bell Telephone Laboratories, Inc. 331 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1929. Price, $5.50.

Darwin stated in the "Descent of Man" that he had collected many definitions of the distinctions between man and the lower animals. He seems never to have published the collection. The distinction most likely to occur to man is that he is the only animal that possesses articulate speech and means of recording it, yet some animals have perfect articulation and some races of men no written language. It is indeed worthy of remark that among the highly artistic paintings that have been found in caves, no indication of inscriptions is seen. In later periods, when written and spoken language was highly developed, inscriptions of all kinds are abundant, even to excess, for the "scribblers" have left evidence of their tendencies even on the sacred figures of catacombs of Rome.

Naturalists who have given special attention to the course of evolution of the human species are in great part of the opinion that it is not the development of the speech center, but of the visual center that has been the main cause of man rising so far above his animal relatives. Speech and hearing are important means of communication, but sight is the most precious of our special senses. There is a French proverb "that in the country of the blind, the one-eyed man is king," but a British author wrote a story to show that this is false for a one-eyed who went to the country of the blind and told the people about the sights around them was adjudged insane.

However, the object of this article is to discuss the merits of the work of which the title is given above. It proceeds from workers in the laboratories of the Bell Telephone Company, and is, therefore, one more reminder of the benefit to science

that has accrued of late from the public spiritedness of the great corporations, which have been devoting much time and money to the advancement of American research. The investigations began about fifteen years ago, and have been zealously pursued in the interval. Special methods have been devised for several phases of the work. Electrical apparatus has been largely employed, and many graphs are given showing the characters of vibrations in human speech. Detailed descriptions of the anatomy of the organs of speech and hearing are given. The necessity for special apparatus was early felt and in the course of constructing and operating these, their application to the development of better service in telephony and phonograph engineering became evident and thus important practical results came out of the theoretical studies. In addition to such practical results, the investigation brought out a wealth of information, new and useful on the fundamentals of speech and hearing.

Though a great deal of new information is presented in the book, the studies, of which it is a report, are far from finished, and Doctor Fletcher tells us that there are fields already in view that will occupy the workers for years to come. An important part of the topics presented in the book has been to determine the degree of precision with which the mind can differentiate and interpret sounds that are very nearly alike. Common experience shows that human beings differ greatly in this respect. Owing to the mingling of many languages in this country, a tendency to slurring speech is all too much in evidence. Teachers of elocution, trainers of children, especially of those who have charge of instruction of those children who come from homes of foreign parents will find the book of much aid.

It is liberally illustrated with graphs, forms of apparatus and tables.

HENRY LEFFMANN.

CASTLES IN THE ETHER. By John Wills Cloud. Revised edition with two appendices. 210 pages, 14 figures, no index, 8vo. Printed for the author by Charles Francis Press, New York, 1928. Price, $5.

In this day and age the term "castle" holds a dual significance. One meaning is that recorded in history, where, in mediaeval times a castle was a concrete (as apposed to abstract) structure and possessed a value intensely practical. It was in truth a fortress and stronghold built of rock on foundations of rock and meant to withstand the attacks of the elements and batterings of the foe. Today we are wont to consider a castle in the abstract sense, it is a figment of the imagination, intangible and romantic. The author has used the term in its second sense and has constructed "castles in the ether" which, compared with "dream castles" and "castles in the air" seem to be of sterner stuff.

Science in its usual meaning concerns itself with the study and correlation of facts so as to produce a system logical in arrangement and structure. Philosophy goes a step further, beyond the facts, and seeks the fundamental causes of the observed phenomena. This is the realm which has attracted the author. His "Castles in the Ether" are founded upon the assumption that ether is a "tangible" substance composed of extremely small but finite particles called ethrons arranged in a definite geometrical way and possessing a rigidity by virtue of vibrations of very high frequency. This is the primary substance of the universe, the stuff of which matter is made, the transmission medium for impulses traveling with the speed of light. With such as a major premise, the author starts out to

interpret the causes of various natural phenomena and show them to be corrollaries of the general theorem of which it is possible to include here only a brief sketch. The ethrons are spherical in shape, packed in the closest possible manner, each sphere in contact with twelve other spheres. Matter is formed by the sudden collapse of the ethrons contained in spaces of a definite magnitude and the particles of matter occupy the vacant spaces or interstices between the ethron spheres. Vibrations due to electromagnetic, heat, light, X-ray and cosmic waves are modifications or modulations of the fundamental vibrations which are an integral part of the ether. Further, it is probable that the formation of matter (collapse of ethrons) occurs at some point in the ether where the frequency is nil (absolute zero) while the transformation of matter to ether occurs at extremely high temperatures where the frequency approaches a maximum. From these assumptions concerning ether and matter as well as the influence of each upon the other, the author evolves an explanation for various natural phenomena such as gravitation, rotation and mutation, inertia and mass, cohesion, polarity and chemical action, matter and energy, molecular motion in gases, electricity, magnetism, surface tension and the spiral rotation of the earth. The fundamental ideas of relativity also seem to be included in the author's scheme of things. Such manifestations as the motion of bodies, their attraction for each other (gravitation), electric and magnetic forces are caused through pressure inequalities in the ether acting in and around objects possessing mass.

It would be a miracle indeed if every reader of this book agreed with the author's explanations of how the ether functioned in bringing about various processes of nature. For, while many will welcome more or less such seemingly rational explanations for processes in general, strenuous objections will be raised over the attempts to explain in more detail certain chemical, physiological and psychological processes.

To anyone at all interested in a philosophy of the universe this book should prove to be mentally stimulating. It is evident that the author's general knowledge extends to practically all branches of science and as a result he has spent much time and thought striving to show a common course and origin for all these apparently unrelated manifestations of natural forces. How well he has succeeded readers of the book may judge for themselves.

The revised edition contains two appendices, A and B. A is a reprint and treats of the genesis of matter in considerable detail. B deals with surface tension as viewed from the standpoint of differences existing between ethereal pressures internal and external to a body.

T. K. CLEVELAND.

STORIES IN STONE: TELLING OF SOME OF THE WONDERLANDS OF WESTERN AMERICA AND SOME OF THE CURIOUS INCIDENTS IN THE HISTORY OF GEOLOGY. By Willis T. Lee, Geologist, United States Geological Survey, Washington, D. C. 226 pages, 49 illustrations, 3 figures, 8vo. New York, D. Van Nostrand Company, 1926. Price, $3.

Here is the opportunity to view the scenic wonders of America from the depths of some comfortable chair. Here, in the realms of the imagination, the reader, accompanied by the spirit of the author, may stand on the brink of the Grand Canyon surveying with mixed feelings of awe and exaltation the kaleido-

scopic panorama of majestic splendor. This would be followed by a trek along the windswept road of the Painted Desert where the rich blue of the skies throws into silhouettes, mesas, buttes, towers and ridges which, in richness and variety of shades would bid fair to rival Jacob's coat of many colors. Not far distant we come upon the Petrified Forest, a natural wonder indeed. Here are found the prostrate trunks of arboreal giants belonging to an age long past. As if at the wave of a great magician's hand they have been transformed from perishable wood to the time-resisting agate, chalcedony, and jasper. If your thirst for rugged splendor is still unappeased you may next go to a wonder child belonging to the Jurassic Age, Zion Canyon. Here, we wend our way along the base of the Vermillion Cliffs flanked by towering buttresses and broad escarpments to come finally upon a scene no mortal might hope to describe adequately, the Temples and Towers of the Virgin, two enormous masses with bases of red sandstone surmounted with towers and domes of white stone soaring upward to the clouds. We are not done yet, in rapid succession the spirit presents to view the Gates of Zion flanked by almost sheer cliffs over half a mile in height; Rainbow Bridge, Mesa Verde National Park, scene of the ancient cliff dwellers, Glacier, Yosemite and Rocky Mountain National Parks, Mammoth Cave and Carlsbad Cavern. Each one unique and marvelously formed.

The Fates were indeed unkind for the author died in June, 1926 before this book was yet in type. A study of geological formations and a correct interpretation of their formative processes have been a source of joy and satisfaction to him. Every page of the book reflects enthusiasm for his subject. Consequently the reader will find that "Stories in Stone" has been written in a style most interesting and a manner most engaging.

The first two chapters are occupied with the question—"What's the Use" (of studying geology) and the answer to the same. Some excellent examples exemplifying the utility of such study also are given. In the chapters following the periods of formation of the various types of landscapes are taken up in chronological order. The author, visualizing the process of rock-strata deposition and the flora and fauna existent at that time, draws freely upon the imagination of the reader yet does not tax it. In these chapters the reader is given the "low-down" on those prehistoric animals which have intrigued so greatly the present-day popular fancy. Judging from the size of the skeletons unearthed they did things in a big way in those early days. Here, also is traced the gradual speeding up of life upon our planet. Beginning with sluggish lizards and ponderous mastodons we see them gradually superseded by winged reptiles (birds) and a fleeter and more agile race of animals such as the progenitors of the modern horse.

A chapter on a new method of observation sketches the adaptation of the aeroplane and aerial photography to geologic exploration. This is followed by an interesting chapter on the legends of creation. The two chief present-day theories of the earth's origin, namely, the nebular and planetesimal are clearly outlined and discussed in an interesting manner. In the final chapter on "Facts, Fancies, and Nebulous Thoughts" there is traced up through the centuries the seemingly eternal conflict between science and dogma. Fossils were believed to be spontaneously generated or the imperfect works of an experimenting Creator. Founders of experimental and natural science were ostracized, forced to retract their teachings or be put to death.

The volume is liberally illustrated with photographs of natural scenery, many of them taken from aeroplanes and possessing a perfection difficult to surpass.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

Vibration Problems in Engineering, by S. Timoshenko. 351 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $4.50.

Fundamentals of Quantitative Analysis, by Walter C. Blasdale, Ph.D. Third edition. 403 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $3.75.

Introduction to Theoretical Physics, by Leigh Page, Ph.D. 587 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1928, price $6.50.

Industrial Carbon, by C. L. Mantell, Ph.D. Industrial Chemical Monographs. 410 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1928, price $4.50.

Enzyme Actions and Properties, by Ernst Waldschmidt-Leitz. Translated and extended by Robert P. Walton. 255 pages, illustrations, 8vo. New York, John Wiley & Sons, Inc., 1929, price $4.00.

The Radio Manual for Radio Engineers, Inspectors, Students, Operators and Radio Fans, by George E. Sterling, edited by Robert S. Kruse. Third printing. 666 pages, illustrations, 12mo. New York, D. Van Nostrand Company, Inc., 1928, price $6.00.

Thyroxine, by Edward C. Kendall, M.S., Ph.D., D.Sc. 265 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929, price $5.50.

A Textbook of Inorganic Chemistry, edited by J. Newton Friend, D.Sc., Vol. XI. Organo-metallic Compounds. Part 1, Derivatives of the Elements of Groups I to IV, by Archibald Edwin Goddard, M.Sc., and Dorothy Goddard, M.Sc. 418 pages, illustrations, 8vo. London, Charles Griffin and Company, Ltd., Philadelphia, J. B. Lippincott Company, 1928, price $14.00.

Steam, Air and Gas Power, by William H. Severns, M.S. and Howard E. Degler, M.E., M.S. 425 pages illustrations, 8vo. New York, John Wiley & Sons, Inc., 1929, price $4.00.

Steam Turbines. A practical and theoretical treatise for engineers and students including a discussion of mercury and gas turbines by James Ambrose Moyer, S.B., A.M. Sixth Edition, Revised. 557 pages, illustrations, diagram, 8vo. New York, John Wiley & Sons, Inc., 1929, price $4.50.

Speech and Hearing, by Harvey Fletcher, Ph.D., with an introduction by H. D. Arnold, Ph.D. 331 pages, illustrations, quarto. New York, D. Van Nostrand Company, Inc., 1929, price $5.50.

CURRENT TOPICS.

Cathode-Ray Oscillographs and Their Uses. E. S. LEE. (*General Electric Rev.*, Aug., 1928.) In the electromagnetic oscillograph a beam of light is made to move over a screen or photographic plate by the motion of a current-carrying element in a magnetic field, the current being in proportion to the effect under examination. Since the element carries a single current such an instrument can record the variation with time of a single quantity. Furthermore, the inertia of the current-carrying element limits the range of response of this instrument to phenomena not having more than about 10,000 cycles per sec. In the cathode-ray oscillograph the moving part that sweeps over screen or plate is a beam of cathode rays that is deflected by the action of an electrostatic or electromagnetic field in proportion to the effect under examination. Since more than one deflecting field can be applied at the same time to the beam and in different planes, records are obtainable that connect two quantities such as volts and amperes. Furthermore, the mass of a beam of cathode rays is negligible and thus inertia ceases to limit the range of application.

There are two general kinds of cathode-ray oscillographs, viz., the low-voltage hot-cathode and the high-voltage cold-cathode types. The rays must be deflected and they must produce an effect on the photographic plate on which they fall, but maximum deflection is antagonistic to maximum photographic effect. The rays have mass, small though it be, and hence their deflection from their rectilinear course while they are traversing the electrostatic or the electromagnetic field is greater the longer they are under the action of the field, that is, the more slowly they move through the field. On the other hand the larger the speed of the rays the greater the effect on the photographic plate. High speed rays produced by high voltages between the anode and the cathode of the tube where the rays are developed are little deflected in the field but strongly affect the plate, while rays due to low voltages on the contrary are much deflected but affect the plate only slightly. From this opposition arise the two types of instruments. In the low-voltage type a heated filament at the cathode is used to facilitate the production of cathode rays at relatively low differences of potential such as 300 to 3000 volts. In the high-voltage cold-cathode type, however, the rays are caused by no auxiliary means but are due to the action of the high potential itself, this being

roughly from 30 to 60 kilovolts. Thus the photographic sensitivity is exalted so that transient electric phenomena can be photographed.

A newly developed oscillograph is described. The parts are mounted on two trucks. The two units weigh 700 lbs. and need a maximum of 4 kw. at 110 volts, 60 cycles. The instrument is for work in the field and the factory during daylight. Records illustrating its results are given among which is one of a voltage wave at a frequency of 1,000,000 cycles per sec. Another shows the building up of current in a resonance circuit at the same frequency. In this the change of current in a millionth sec. can readily be followed.

This high voltage instrument lends itself to investigations of time-voltage characteristics of spark gaps and insulation, of transmission disturbances, of lightning arrester phenomena, of conditions in circuits at radio frequencies, of telephone protection problems, of mechanical vibrations, of pressures in guns and gasoline engines, of circuit breaker and switching results and of discharge phenomena.

G. F. S.

The Large Electromagnet of the Academy of Sciences. A. COTTON. (*Comptes Rendus*, July 9, 1928.) Of course the design of a powerful electromagnet is determined by the purposes it is to serve. The one planned by Kapitza at Cambridge produces fields of several hundred thousand gauss that exist only inside of small coils and for about 1/100 sec. To be generally useful for researches, however, the space where the strong field is produced must be as large as possible. This new French model sacrifices strength of field to general usefulness. As long ago as 1912 Cotton obtained the reservation of a part of a legacy for the building of a large electromagnet, and a committee developed a preliminary sketch of an instrument with iron cores a meter in diameter. Then came the invasion of France by Germany. After the War the projeet was resumed and a million francs were granted from the funds of Pasteur Day. New information was then available and a fresh study was needed. Accordingly a committee was again appointed. On it were such men as Picard, Appell, d'Arsonval, Branly, Blondel, Weiss, Brillouin, Ferrié, de Broglie, Claude and Cotton. After the general design had been selected a quarter-size model was constructed upon which experiments were made that led to modifications of the first design. By the beginning of 1927 the final plans were ready but prices had gone up so that pecuniary troubles were frequent. These were overcome and the electromagnet is now installed at Bellevue at the National Office of Scientific and Industrial Researches and of Inventions. The

cores are in the form of truncated cones, tapering in diameter from 121 to 75 cm. Each core weighs 3.5 tons and is 65 cm. long. Of electrolytic copper 8.6 tons are used, the frame weighs 50 tons; altogether 105 tons of iron enter into the structure whose total weight is 120 tons. The windings are hollow tubes of copper through which water flows to remove the heat. 400 amperes flow ordinarily under 240 volts pressure, the power being thus 100 kw. As there are 1250 turns, the number of ampere-turns is 500,000. Ferro-cobalt is used in the central part of the pole pieces. The measured strength of field between the pole pieces is 46,400 gauss through a cylindrical space 4 cm. in diameter and 2 cm. long. The rise of temperature is 25° C. The entire electromagnet is about 6.3 m. long with a square cross-section 2.75 m. on a side. Connected with the electromagnet is a vertical spectrograph installed in a well 9 m. deep, by which very delicate optical researches can be conducted.

It is claimed that this instrument surpasses any other hitherto available in size, power and facilities for operation. G. F. S.

The Luminescence of Water and of Carbon Disulphide Due to Gamma Radiation. L. MALLET. (*Comptes Rendus*, July 23, 1928.) Two years ago the author stated that water and certain organic substances luminesce with white light when acted on by γ-rays from radioactive substances. On account of its feebleness this white light could not be resolved spectroscopically by ordinary apparatus but the author has the use of a special instrument designed by Fabry that gave adequate images on Lumiere plates with exposures of from two to four days. The rays emanated from 250 grams of radium sulphate. In the case of water as well as of carbon disulphide the substance acted on by the rays emitted a continuous spectrum covering the entire visible field and all of the ultraviolet that was not absorbed in the apparatus. The luminescent radiation was richer in the short wave-lengths than the light of a half-watt lamp. It appears that the emission of visible and ultra-violet radiations by bodies acted on by gamma rays is a general phenomenon. G. F. S.

The Element of Time in the Photoelectric Effect. E. O. LAWRENCE AND J. W. BEAMS. (*Phys. Rev.*, Sept., 1928.) "How soon are electrons emitted from a metal surface after it is irradiated by light and in what manner does the electron emission persist after cessation of the illumination? The experiments described below have given an answer to this fundamental query." A method was needed of illuminating a metal surface for time intervals

of about a ten-millionth of a sec. and then of finding exactly when in respect to the illumination electrons were ejected. By the use of crossed Nicol prisms between which were two Kerr cells with the normals to their surfaces at rght angles to each other it was arranged to let the light from an electric spark pass through the combination for a length of time depending upon the interval between the instants when the two cells, connected by wires of different lengths with the spark gap, began their discharge. This interval was controlled by varying the length of these wires. The flashes of light coming through when the spark gap was connected to the secondary of a transformer irradiated a potassium hydride surface. The emitted electrons made their way to a collecting electrode joined to an electrometer. "Determining what length of wire was necessary to obtain an appreciable photoelectric current to the electrometer was therefore a measure of the instant at which the electrons first were emitted." The wire here mentioned was connected to the spark gap. Its length determined the time of arrival from the spark gap of the electric potential wave which in turn governed the relative potentials of the surface emitting electrons and of a grid surrounding the collecting electrode. It was only while the plate was at a lower potential than the grid that electrons passed through it to the collecting electrode.

It is thus possible to take measurements and construct curves connecting the strength of the electron current with the time after the beginning of the spark. From one such curve it is seen that the light flash and the photoelectric emission began only one-two hundred millionth of a sec. apart. It is true, however, that according to the curve the spark was the later to occur. A careful consideration of this and of other possible errors in the measurements leads the authors to state that the light flash and the beginning of electron emission are instantaneous with a possible difference of not more than three billionths sec., and that the emission lasts not more than 10^{-8} sec. after the light has been cut off. G. F. S.

The Velocity of Sound in Liquids at High Frequencies by the Sonic Interferometer. J. C. HUBBARD AND A. L. LOOMIS. (*Phil. Mag.*, June, 1928.) The method hereafter described makes possible the measurement of the velocity of sound waves in relatively small quantities of liquids. In addition the accuracy attained is such that there seems reason to hope that the method may be used for purposes of analysis. Direct measurements of sound velocities require large bodies of the substance for the experiment with multiplied difficulties in finding the temperature and other physical data of the liquid

under experiment. Even resonance methods for audible frequencies have demanded apparatus of large dimensions so that only the commoner liquids could be examined. In addition it was necessary to correct for the influence of the material and dimensions of the apparatus upon the observed wave-length and different observers used different correction formulæ so that their results do not agree even when they are comparable.

The present paper summarizes the results obtained in the Loomis Laboratory during the summer of 1927. In a liquid contained in a cylindrical chamber compressional waves were set up by the vibration of a quartz plate 50 mm. in diameter. This piezoelectric plate was placed between two electrodes one of which was grounded while the other was joined to a point "on the coil of a high-frequency oscillating electrical circuit." The plate was horizontal and at the bottom of the cylinder of liquid. A horizontal piston above the plate was adjustable by a micrometer screw. An essential prerequisite for satisfactory operation was the absence of gas bubbles between the plate and the liquid above it. The sound waves, about 3 mm. in length, passed through the liquid to the piston and, after reflection there, returned toward their source, interfering with the oncoming waves. The tuning of the interval between piston and plate for exact resonance could be done by any one of several electrical methods of which a double heterodyne method was found most suitable. "In practice, the reaction is so sharp at the node that settings may be made by ear within a few thousandths of a millimeter. Under usual conditions the precision obtainable in the value of the half wave-length from such readings is about one part in five thousand." For example, with mercury at 20° C. seven determinations of the half wave-length show the same value to the third decimal place, viz., 0.165 cm. and differ only in the next decimal place. The smallest value found was .16570 and the largest .16583. The mean velocity is 1451.0 m./sec.

The velocity of sound was obtained in water from zero to 40° C. It increases linearly up to about 15°; after this the increase is less rapid. The velocities at 0°, 20° and 40° are respectively 1407, 1484.2 and 1530.3 m./sec. In the case of mercury the velocity decreased linearly with increase of temperature, the velocities at 0° and 70° being 1460.2 and 1427.7 m./sec. Five different aqueous solutions of NaCl were examined. The greater the salt content the higher the velocity. Similar results were obtained for NaI. At all the temperatures used the NaCl solutions showed higher velocities than water, but a solution of 30.5 per cent. NaI at 25° C. gave the same velocity as water at that temperature, while for lower temperatures the solution had higher velocities and for higher temperatures smaller velocities than water at corresponding temperatures.

This method makes it possible to get the velocity of sound without the admixture of effects due to the size and materials of the containing vessel and gives results of such accuracy that several thermodynamic quantities can be calculated from them.

G. F. S.

The Normal Photo-Electric Effect. P. LUKIRSKY and S. PRILEZAEV. (*Zeit. für Physik*, Vol. 49, Nos. 3 and 4.) When quanta of radiant energy impinge on bodies electrons are torn away from them. In this action two distinct cases are to be distinguished. When the electrons are bound by merely weak forces while the energy of the incident quanta is large, the Compton Effect manifests itself, only a part of the energy of the incident quantum being transferred to the electron and the remainder going off as a quantum of longer wave-length. In the other case, when the energy of the quantum falling on the body is not much greater than the energy requisite to free an electron from the body. The quantum of radiation is then expended in full on an electron. The electron receives a velocity upon leaving the body, but before this can occur it must be separated from its atom and a little later must make its way through the surface of the body into outer space. Einstein's equation relating to this series of exchanges is $\frac{1}{2}mv^2 = h\nu - p_1 - p_2$.

The left side of the equation is the kinetic energy of the emerging electron, p_1 is the energy spent in separating the electron from the atom and p_2 is the work done in getting the electron through the surface of the body. This equation is known to apply to all frequencies of radiation from those of the visible spectrum to those of gamma radiation.

In the present experiment a spherical condenser was used. The inner sphere was the body on which radiation fell and from which electrons were emitted. The two spheres had respective diameters of 11 and 1.5 cm. What becomes of the issuing electrons depends on the strength and direction of the electrical field between the two plates of the condenser. If the direction of the field is such as to retard the electrons it is possible to adjust its strength so that no electrons at all will pass from the inner to the surrounding sphere. In this case an electrometer joined to the inner sphere would show no current in spite of its ability to indicate 10^{-13} ampere. In getting the retarding potential, account had to be taken of the contact difference of potential between the inner sphere and the silvered sphere surrounding it. From the curve connecting the applied difference of potential and the current flowing from the inner sphere considerable interesting information can be deduced. The

value of Planck's constant, h, is calculated to have the following values in 10^{-27} ergs per sec. for the metals named,—Al, 6.539; Zn, 6.556; Ni, 6.546. The mean of all the determinations is 6.543×10^{-27} ergs/sec., whereas optical methods give 6.545×10^{-27} ergs. sec.

As stated above the energy of the incident quantum gives kinetic energy to the ejected electron, frees it from its atom and forces it through the surface of the body. If the quantum is equal to the sum of the energies needed for these two last acts, no energy is left over to provide velocity for the electron. Let radiation of longer and longer wave-length be made to fall in succession on the body. The value of the quantum grows progressively smaller, because it equals the product of Planck's constant by the frequency of the radiation. Thus eventually a wave-length will be found for which the quantum is completely expended in freeing the electron and getting it through the surface. The electron cannot leave the body as there is no energy to put in it motion. Again from the curves this limiting wave-length can be obtained. For platinum it is 3018 Å. and for aluminium 4132 Å. Besides this the contact difference of potential between the metal of the inner sphere and the material of the outer sphere can be computed, and also that between any two metals used for inner spheres.

An important theoretical conclusion drawn from the results is that "In the photo-electric effect due to optical wave-lengths the same electrons are torn from the metal that are responsible for its electrical conductivity." A study of thin films in comparison with massive pieces of metal indicates that the electrons set free in the interior of the metal lose some of their velocity there.

G. F. S.

Evidence that the Cosmic Rays Originate in Interstellar Space. ROBERT A. MILLIKAN AND G. H. CAMERON. (*Proc. Nat. Acad. Sciences*, August, 1928.) On the assumption that the cosmic rays are due to the formation of common elements from positive and negative electrons, the next question is "where are these creative processes going on?" There are two possible localities, in the stars where temperatures, pressures and densities are very high or in interstellar space where these three quantities are very small. Two reasons are given for eliminating the stars from consideration: (1) If atom-building with the consequent production of cosmic rays is favored by the conditions that hold inside of stars, then the sun, the star nearest to us, should send to the earth more rays than any other star. It is, however, true that the intensity of these rays is not affected by the change from noon to midnight. "This can

only mean that the conditions existing in and about the sun, and presumably also in and about other stars as well, are unfavorable to the atom building processes which give rise to these rays. Since, however, the rays do come to us at all times, day and night, and, according to all observers, at least very nearly equally from all directions, there is scarcely any escape from the conclusion that the atom-building processes giving rise to the cosmic rays are favored by the conditions existing in interstellar space." (2) The hardest cosmic rays are completely absorbed by passing through about 70 meters of water. If such rays were produced inside of stars they would be absorbed on their way out to the surface unless they were developed in the outer layer of the star so near to the surface that the absorption between their origin and the surface would be not greater than that of 70 m. of water. Measurements have shown that the energy of the cosmic rays reaching the earth amounts to about one-tenth of the energy coming to our globe as light and heat from all the stars except the sun. "This last fact means that if the cosmic rays have their origins within the stars, they cannot, even at the points of their origin, have an intensity more than ten times that which they have when they reach the earth's atmosphere, for if they had then the cosmic-ray energy transformed into heat by absorption on the way out would yield a total heat outflow from the stars larger than the observed ten to one ratio."

Jeans and Eddington have sought the origin of the heat of the stars in the process of annihilation of atoms occurring within them, with the transformation of mass into radiation. The authors have, however, been unable to find among the cosmic rays the frequencies that correspond to this process. This failure in no way counts against the possibility of the process occurring inside of stars where the radiation produced would be absorbed before it could escape into outer space. By combining the idea of the formation of matter in interstellar space with that of the transformation of matter into radiation within stars the following incomplete cycle is suggested:

"1. Positive and negative electrons exist in great abundance in interstellar space. (See the evidence of the spectroscope).

"2. These electrons condense into atoms under the influence of the conditions existing in outer space, viz., absence of temperature and high dispersion. (See evidence of the cosmic rays.)

"3. These atoms aggregate under their gravitational forces into stars. (See evidence of the telescope.)

"4. In the interior of stars, under the influence of the enormous pressures, densities and temperatures existing there, an occasional positive electron, presumably in the nucleus of a heavy atom, falls

into complete coincidence with a negative, i.e., transforms its entire mass into an ether pulse the energy of which, when frittered away in heat, maintains the temperature of the star and furnishes most of the supply of light and heat which it pours out. (See evidence of the lifetimes of the stars.—Eddington-Jeans.)"

The authors direct attention to the absence of any evidence for the formation of hydrogen from radiation at least so far as their experiments go. G. F. S.

Resolving into Separate Drops the Cloud Paths Caused by Alpha Rays. O. KLEMPERER. (*Z. f. Physik*, Vol. 45, Page 225.) When a volume containing water vapor is sufficiently expanded a cloud is formed provided that proper nuclei are present on which the water may condense. When beta rays pass through air the resulting ions serve as such nuclei. About 100 pairs of these ions are produced per cm. of path and they can be counted by moderate magnification. Since alpha rays develop 100 times as many per cm. the resolution of the resulting path into individual droplets has not hitherto been accomplished. To attain the desired separation three courses were followed, 1. the moist gas, hydrogen, was used at as low a pressure as possible so that as small a number as possible of ions would be produced in a unit of length. The final pressure used was about 7 cm. of mercury. 2. In photographing the cloud path the highest possible magnification was used, and 3. The photograph obtained was in its turn magnified to the limit. A reprint of a photograph is shown in which the distances between drops are magnified 260 times. From it the author derives the formation of about 16,000 pairs of ions per cm. of path of alpha rays in normal air. The mean diameter of the cloud path comes out as equal to 4×10^{-3} cm.

G. F. S.

Selective Adsorption from Gaseous Mixtures by a Mercury Surface formed in the Mixture. M. L. OLIPHANT. (*Phil. Mag.*, Sept., 1928.) When a mercury surface increases in area molecules recently in the interior of the liquid are brought to the surface. Their orientation with respect to their fellow molecules probably determines the forces to which they are subject. Moreover it is very unlikely that all the fresh molecules arrive at the surface in any definite alignment. It is therefore to be expected that from the moment of the formation of the new surface onward there will proceed a rearrangement of the molecules that will result in the establishment of a surface having minimum energy. The consequent rapid fall of surface-tension will be difficult to follow by measurement. Let the expansion of the area of the mercury surface

take place, however, in contact with a gas. It may occur that a molecule reach the surface with an end toward the gas then grasps a molecule of the latter, i.e., produces adsorption. This union delays the attaining of the condition of minimum energy for the surface, and renders it easier to trace the concomitant changes in surface-tension "Thus Popesco has shown that five seconds after the formation of a large drop of mercury in contact with a gas the surface tension is above 500 dynes/cm., and that this falls exponentially to a final value of about 400 dynes/cm., the time taken varying with the gas. On the other hand, Harkins using the 'drop-weight' method for measuring surface-tension, does not observe any large difference between the surface-tension of a drop formed *in vacuo* and one formed in a gas. This would indicate either that the gas is not adsorbed at the surface so as to interfere with its orientation, or that the assumed abnormally high initial surface-tension due to the random orientation in the fresh surface does not actually exist. One of the methods for measuring the surface-tension must give the wrong result, and the following experiments have been carried out in order to test whether the adsorption of gas does take place at an expanding mercury surface."

Mercury issued from a nozzle having 25 holes at the rate of 20 drops per sec. through each hole. The drops fell through a mixture of carbon dioxide with argon or hydrogen and collected in a pool at the foot of the tube. If one of the gases in the mixture is more readily adsorbed than the other, then, where the drops form molecules of this gas will become attached to them and will be conveyed to the pool of liquid below where they will be disengaged. Thus the composition of the mixture changes with the falling of the drops. The adsorbed gas disappears from the vicinity of the nozzle and is present in greater proportion at the lower end of the tube. Following the procedure of Schofield a stream of the mixed gases is supplied to the middle of the tube, where it divides into an upward and a downward stream of equal velocities. The two streams are conducted to the two tubes of a Rayleigh interferometer, capable of detecting a change of .001 per cent. in the CO_2 content of a mixture of hydrogen with 2 per cent. of carbon dioxide. The shift of fringes in the interferometer enabled the change of composition to be calculated. From the number of drops per sec., the volume of mercury falling per sec. and the change in composition the number of carbon dioxide molecules attached to each sq. cm. of mercury drop is calculated to be $.7 \times 10^{15}$. From the already known diameter of the mercury molecule this is interpreted to mean that the adsorbed CO_2 layer is one molecule thick. The experiment clearly shows that fresh mercury surfaces do adsorb CO_2 and that

the forces concerned cause the gas to remain attached during a fall through a distance of 50 cm. Moreover adsorption is selective as is demonstrated by the change in the composition of the gas. The experiment speaks against Harkins' method of measuring surface-tension. G. F. S.

The Foundation of Electromagnetism. (*Isis*, June, 1928.) To Hans Christian Oersted we owe the discovery of the magnetic effects of the electric current. He was born on a Danish island in 1777, became professor in the University of Copenhagen and died in 1851. "The experiments which he began in April 1820 are among the most memorable in the whole history of science. They enabled him to correlate two departments of natural philosophy, hitherto separate, electricity and magnetism—and thus to carry one step further the unification of knowledge."

There is given a facsimile of a lithographic portrait of Oersted made by his compatriot Bearentzen who in making his likenesses used to draw directly on the stone. Two papers of Oersted are presented in facsimile, one his account in Latin of his discoveries and the other the English translation of the same paper, sent to the Annals of Philosophy. Both bear the date of July 21, 1820, and both describe the author as "Knight of the Order of Danneborg, Professor of Natural Philosophy, and Secretary to the Royal Society of Copenhagen." The title in English is "Experiments on the Effect of a Current of Electricity on the Magnetic Needle." This, however, is a free translation of the Latin heading "Experimenta circa Effectum Conflictus Electrici in Acum Magneticam." What the Latin words for "conflict of electricity" meant is explained in the English text where in regard to a wire connected to the ends of a galvanic battery it is said "To the effect which takes place in this conductor and in the surrounding space, we shall give the name of the *conflict of electricity*." The 'electric conflict' then includes both the electric current and its magnetic field. For example it is said "It is sufficiently evident from the preceding facts that the electric conflict is not confined to the conductor, but dispersed pretty widely in the circumjacent space." It is indeed surprising to note how well Oersted gets along without any equivalent for the modern expression 'the electric current.' He is definite by stating which end of the wire receives positive or negative electricity, though references to negative electricity preponderate.

It seems that others had previously sought in vain for an effect of open galvanic circuits upon the magnetic needle. Oersted in the winter of 1820 found an effect to occur provided the circuit be closed, or, as he quaintly phrases it, "the galvanic circle must be

complete." He repeated the experiments using a stronger battery and gives the names of six men who were witnesses. This method of attesting the credibility of discoveries has its merits. Had Blondlot and Charpentier followed the example of the Danish investigator perhaps the myth of the *N* rays would not have arisen a quarter of a century ago.

The science of electrical measurements was not yet born for we read "A smaller apparatus will answer provided it be strong enough to heat a metallic wire red hot." A straight piece of wire conveying the electric current was tried in various positions in relation to the needle and the deflections noted. The needle was seen to be deflected in a horizontal plane or a vertical plane according to the location of the wire and very acutely the conclusion is drawn that "The effect cannot be ascribed to attraction" and later "This conflict performes circles; for without this condition, it seems impossible that the one part of the uniting wire, when placed below the magnetic pole, should drive it toward the east, and when placed above it toward the west; for it is the nature of a circle that the motions in opposite parts should have an opposite direction." The nature of the wire made no difference for "Wires of platinum, gold, silver, brass, iron, ribbons of lead and tin, a mass of mercury were employed with equal success." Many different substances were interposed between the current and the needle but all tried were without effect. No ferromagnetic material was tested. A brass needle and needles of gum lac and of glass in turn replaced the magnetic needle but all remained undeflected by the current.

Oersted considers but rejects as valueless for explanatory purposes "a motion in circles, joined with a progressive motion, according to the length of the conductor." This, however is surprisingly reminiscent of one modern mnemonic device for connecting the deflection of the needle with the direction of the current.

G. F. S.

An Attempt to Polarize Electron Waves by Reflection. C. J. DAVISSON AND L. H. GERMER. (*Nature*, Nov. 24, 1928.) Now that certain striking resemblances between electrons and light waves have been shown to exist it is quite in order that search should be made in the endeavor to find additional similarities. The authors who proved electrons to be reflected from crystals much as light waves are reflected from mirrors have looked for evidence that upon the reflection of electrons from a crystal some change occurs that is analogous to the polarization imposed upon light when it is reflected from glass. They report "So far as our observations go, there is no polarization of electron waves by reflection." G. F. S.

Detecting Leaks in Glass Vacuum Apparatus. P. SELENYI. (*Zeit. für Physik*, Vol. 48, page 743.) Glass tubes and vessels in which a vacuum is produced and maintained are likely to develop leaks that are difficult to locate. The author presents a method of detection which he devised in connection with the manufacture of incandescent lamps. By Tesla currents the entire vacuous space is made to glow with a color characteristic of the contained gas. Now if a different gas is leaking in its entrance will manifest itself by the appearance of a different color. For rapid recognition the two gases should give sharply contrasting colors. Thus to the red light given by air at low pressure the bluish color of carbon dioxide provides an easily visible contrast. In practice it was found convenient to have the CO_2 inside the apparatus and the air outside. When the air found its way into the vessel a red patch showed itself at once surrounding the place of entrance. This was effective in locating even the slightest leak especially when an artifice discovered by the women workers was used namely that of touching with the hand the part of the apparatus to be examined. If it is inconvenient to have the apparatus filled with carbon dioxide the difference of colors may be got by using air inside and running the CO_2 over the outside from a tube. G. F. S.

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